EXPERIMENTAL SCIENCE

I. PHYSICS

SECTION II. HYDROSTATICS

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EXPERIMENTAL SCIENCE

I. PHYSICS

BY

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SECTION II. HYDROSTATICS

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PREFACE

TO SECTIONS 1, 2, 3 AND 4

THE following introductory course of Experimental Science is divided into three parts—I Physics, containing sections on (1) Measurement, (2) Hydrostatics, (3) Mechanics, (4) Heat, (5) Light, and (6) Sound; II Chemistry, and III Electricity and Magnetism.

The book is based on the practical experience of practical teachers and every care has been exercised to provide a set of lessons which will not only educate the pupil but also maintain interest and attention.

In the particular Secondary School where the first part of the course (Sections 1, 2, 3 and 4) has been put to the test by about 450 boys working in 16 classes (Forms III and IV), it has been found that the average pupil can, during two years, complete nearly the whole of those sections by working for four periods per week, two of the periods running consecutively for laboratory practice. When, however, only four periods per week are allotted to science work, a part of the Section on Mechanics is deferred until the third year.

Five of the writer's colleagues, specialists in Mathematics and Science, have collaborated with him in reading proof-sheets and in giving the benefit of their experience and kindly criticism; and he wishes gratefully to acknowledge the help of Mr L. Caldecott, B.A., B.Sc., Mr T. V. T. Baxter, M.A., B.Sc., Mr W. R. Cooper, B.A., Mr A. C. Baggley, M.A. and Mr J. M. Moir, M.Sc.

The writer is especially indebted to Mr Lawrence Caldecott, Senior Science Master at the Liverpool Collegiate School, who has prepared, and has tested in his classes, the

carefully graduated examples which form, in the writer's opinion, one of the most important features of the book. Continued and systematic working through these examples is essential and will ensure success for the pupils. Mr Caldecott has also given untiring assistance in contriving details of laboratory method which will help beginners to obtain with certainty accurate results even in difficult experiments such as finding the Coefficient of Expansion of a Gas and the Latent Heat of Vaporization of Steam.

The writer acknowledges with thanks the permission of Messrs F. E. Becker & Co., Hatton Wall, Hatton Garden, E.C., to use diagrams Nos. 90, 91, 107, 138, 142–6, 160, 169, 178 *a*, 181, 188, and 197.

The author believes that the experiments chosen throughout the book are presented in a newer and simpler form perhaps than heretofore, and that this alone should justify the publication of another text-book on Experimental Science.

The following are among the examinations which may be successfully taken after carefully working through Experimental Science, Parts I and II: Oxford and Cambridge Local Examinations—Experimental Science (Junior), Chemistry (Junior), Heat (Junior, and Senior); Experimental Science and Physics, Northern Universities Examination Joint Board; Army Qualifying Examinations, Naval (Boy Artificers) and Aircraft Apprentices, Board of Education, College of Preceptors, and Examinations for Junior County Scholarships, which require Physics, Chemistry and Practical Mathematics.

S. E. BROWN.

LIVERPOOL,
May 1927.

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HYDROSTATICS

CHAPTER VI.

PROPERTIES OF MATTER.

25. Force.

In considering the properties of matter we shall constantly use the word—*force*. What is a *force*? The inability of matter to change its state of rest or of motion (§ 24) is called its **inertia**—*forces* are necessary to change that state. Let us give an instance. A stone resting on level ice requires *force* to put it in motion, but once moving, if the ice is perfectly smooth and if there is no air to cause resistance, the stone will continue to move at a uniform speed, unless some *force* either quickens its pace or lessens it until finally the stone is brought to rest. In reality, the air presses against the stone and friction drags on it: both *forces* of *pressure* and of *friction* help to stop it.

General properties of matter. In § 24, it was stated that, in addition to possessing *inertia*, *matter occupies space* and *attracts* other forms of matter (*i.e.* it *has weight*). In our study of Chemistry we find that *matter is indestructible* (*Exp. Chem.* § 34). **Matter exists in three states**—*solid*, *liquid* and *gaseous*. **Solids** possess **rigidity**, *i.e.* they offer resistance to forces which tend to change their shape or their volume: **Liquids** and **Gases**, which are classed together as **Fluids**, offer no lasting resistance to such forces.

In the study of **Hydrostatics** we investigate how forces act on *fluids* and keep them at rest.

36. The Constitution of Matter.

The gaseous state. We know that ice (a solid) may be turned into water (a liquid) by heat and that further heating converts water into steam (a gas). The reverse process of cooling changes steam to water and water to ice. The effect of heat on all solids is to convert them finally into the gaseous state. The effect of cooling gases is finally to convert them to the solid state. This solar system of ours consisting of the sun, the planets with their moons and the asteroids is supposed to have been once gaseous. It is losing heat and finally will all become solid; for instance, the present oceans of our earth will be ice throughout and on them at first will rest an ocean of liquid "air" which further cooling will convert to the solid state. It is simplest therefore to begin our study of the constitution of matter by considering the gaseous state, where matter "is without form."

Matter is supposed to be made up of little particles called **molecules** (Lat. = little masses), which are far too small to be seen by the most powerful microscope. These molecules are said to be in constant motion and, in the gaseous state, have free paths in space. They strike against each other and against the walls of the vessel which contains them, thus producing a constant battering or bombardment which causes pressure (*e.g.* in an inflated football or toy balloon). The molecules are supposed to be perfectly **elastic,** *i.e.* they lose none of their energy of rebound when they collide with any object; consequently the pressure caused by their bombardment remains constant if the conditions are unchanged. Gases are easily compressed and the pressure and density rise as the molecules are more confined. Gases possess no rigidity, as stated above, consequently they can have no definite shape, and they completely *fill the vessel* in which they are placed. Gases readily mix with or **diffuse** into each other.

Exp. Pull out the piston of a bicycle pump, close the nozzle with your finger and push in the piston. The air within is easily *compressed*, but on

releasing the piston, it flies back to its original position, thus showing the *elasticity* of the air as well as the *pressure* of the confined gas.

37. The liquid state.

A gas by compression and cooling may be converted into a *liquid*; its volume is much reduced in the process, thus showing that the molecules are more tightly packed into a given space in a liquid than in a gas. In the reverse process, as for instance when water is boiled, the steam occupies many hundred times the volume of the water from which it is obtained. Liquids however are practically *incompressible* and do not expand except under the action of heat, consequently they have a definite volume, but as they possess no lasting rigidity they have *no definite shape*. This absence of rigidity causes them to flow in a vessel and fit themselves to its shape but the upper or *free surface is horizontal.* A liquid is said to *find its own level,* thus, if a number of vessels (Fig. 39) communicate with each other and a liquid is poured in, the level LL_1 of the free surfaces will be horizontal and the same for all. This property is used in levelling instruments (Fig. 40) and in supplying towns with water from a reservoir situated at a higher altitude than the houses of the town.

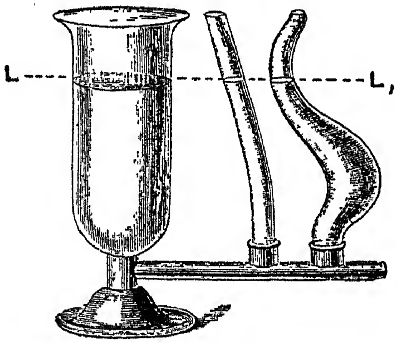


Fig. 39.

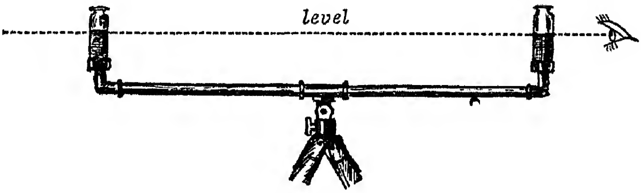


Fig. 40.

Some liquids *pour* more readily than others; they are said to differ in **viscosity.** Thus treacle, lava, honey and seccotine are more *viscous* than water and petrol. Pitch (cobbler's wax), vaseline, train-oil and soft-soap are highly viscous liquids.

38. Cohesion, Surface Tension, Capillarity, Diffusion.

The force of attraction between the molecules of a body is called **cohesion.** Liquids exhibit slight cohesion, gases none. This attraction of the molecules for each other and the absence of rigidity cause a small drop of a liquid to assume a *spherical* shape.

At *c* the centre of the drop (Fig. 41), a molecule is pulled or attracted in all directions by other molecules surrounding it; but at or near the surface (A, A') a molecule will be pulled by cohesion towards the interior of the drop, the forces being evenly distributed about the radius $A'c$ at the point A'; hence there is a constant tendency for the drop to contract radially towards the centre. At any point on the surface (A) there will be forces equal but opposite in direction (T, T), so that the surface behaves as though it were covered by a thin skin pulled tightly in every direction. This pull along the surface, called **surface tension,** is clearly seen in a soap bubble. The bubble slowly collapses if the enclosed air has access of escape. Surface tension pulls the drop into the shape of the solid which has least surface for a given volume, viz. that of a *sphere.* If the attraction of the molecules for each other (*cohesion*) is less than their attraction to the sides of the vessel containing the liquid (*adhesion*), the liquid wets the vessel, as for instance is the case with water in a glass: with mercury however in a glass vessel the reverse is seen—mercury

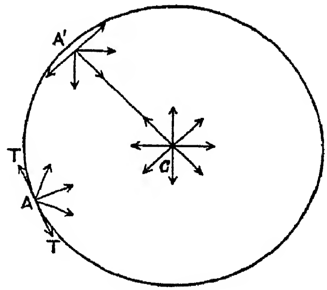
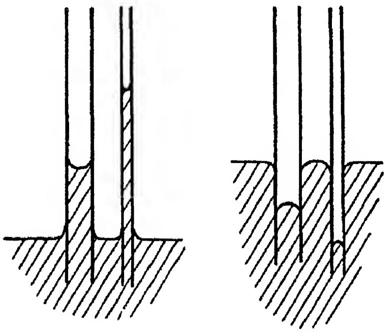


Fig. 41.

does not wet glass because attraction of cohesion in mercury is greater than that of adhesion between mercury and glass.

Exp. Capillarity. Heat pieces of glass tubing in the blowpipe flame and draw them out into fine capillary tubes (*Exp. Chem.* § 3). Hold the ends of these tubes in (1) coloured water, (2) coloured alcohol, (3) mercury. Note that the liquid rises in the tubes in water and alcohol but is depressed in the case of mercury. These results are said to be due to *capillarity* (Lat. *capilla*: a hair) where the pull upwards or downwards is due to surface



Capillary tubes in water or alcohol.

Capillary tubes in mercury.

Fig. 42.

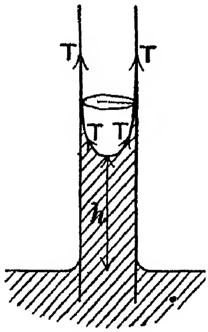


Fig. 43.

tension (Fig. 42). The finer the tube the higher the liquid rises[1]. In the wick of a lamp the oil rises because of capillary attraction.

[1] Let T be the surface tension in grams across 1 cm. length. In a capillary tube of radius r (Fig. 43) placed in water which rises to a height h, there is a pull of capillarity up the tube of

$$T \times \text{circumference of tube} = 2\pi r T \text{ grams,}$$

which supports the column of water of

$$\text{volume} = \pi r^2 \times h \text{ c.c.}$$

and of

$$\text{weight} = \pi r^2 h \text{ grams,}$$

$$\therefore\ 2\pi r T = \pi r^2 h,$$

$$\therefore\ \frac{2T}{r} = h,$$

$\therefore$ the smaller r becomes the greater h becomes.

Exp. Porosity and Diffusion. Having closed one end of each of two pieces of $\frac{3}{4}$ inch tubing with thin plugs of Plaster of Paris paste, allow the paste to set and dry for some hours. To all appearances the plugs are solid; they may however be shown to be *porous* (*i.e.* traversed by minute passages between the molecules) as follows: (1) Fill one of the tubes with coal-gas and place it vertically with its open end dipping below the surface of water in a beaker (Fig. 44). The coal-gas escapes through the plug more rapidly than air can enter; water consequently rises in the tube. After some hours air will have completely replaced the coal-gas. (2) The reverse process is shown by supporting the second tube vertically with its end dipping under the water, and surrounding it by a cylinder full of coal-gas. Gases pass in both directions (*diffuse*) through the plug but coal-gas enters more rapidly than air escapes, hence bubbles come out at the bottom of the tube.

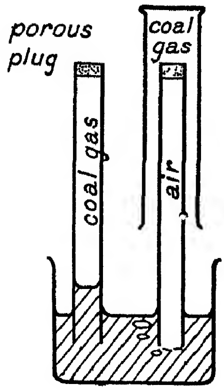


Fig. 44.

39. The Solid State.

Solids possess **rigidity** (§ 30) to a varying extent; steel, for instance, is more rigid than copper, and copper than india-rubber. Solids, like liquids, are only very slightly *compressible.* Solids vary in their capacity for recovery of shape after being squeezed, twisted or pulled: this property of recovery is termed the **elasticity** of the substance. Gold, silver and copper may be drawn out in fine wire and are said to be **ductile**; such metals are as a rule also **malleable,** *i.e.* they may be hammered into thin sheets; gold leaf has been estimated to have a thickness of less than $\frac{1}{250,000}$ inch.

Exp. Tie two long thin wires of copper and of steel respectively, of equal length and thickness, to a beam at the top of a high room. Suspend a scale-pan from each wire and place weights in the pans. Note that the distance of the pans from the floor lessens as weights are added. Remove the weights; there is recovery in both wires, as regards length, provided only small weights have been added. On the addition of more weights the copper wire becomes permanently stretched and is said to have passed its

limit of elasticity, but the steel wire recovers. Further addition of weights breaks the steel wire but the copper wire will probably be drawn out into a still finer wire until the pan reaches the floor, thus showing that copper, although less *elastic* than steel, possesses *ductility* to a much greater extent.

Evaporation of liquids and the pressure which their vapours exert is referred to in the section on Heat and also in *Exp. Chem.* §§ 17, 29. Diffusion of gases has already been mentioned in this chapter. In liquids, the molecules mix less rapidly even when the liquids are stirred; in *solids*, *diffusion* has been proved to take place but to a very limited extent and only after long lapse of time. It has been proved that, if a piece of pure lead and a piece of pure gold are kept in close contact and long afterwards separated, the lead contains traces of gold and the gold contains traces of lead. It is also a well-known fact that ice lessens in volume by evaporation, although it is kept solid at a temperature below its melting point, thus showing that even in solids, the molecules are in motion and that near the surface they may leave the solid altogether and either pass away into the atmosphere or penetrate the interstices or spaces between the molecules of an adjacent solid.

Examples VI.

1. Explain the difference between Solids, Liquids and Gases.

2. What practical use is made of the fact that 'water finds its own level'?

3. Why is the surface of the mercury in a barometer curved?

4. Prove that capillarity will cause a liquid to rise higher in a narrow tube than in a wide one.

CHAPTER VII.

FLUID PRESSURE. PRESSURE IN LIQUIDS.

40. How to measure pressure.

The **pressure** exerted by **the wind** may be measured by the following method:

Ex. i. Suspend a square kite (K) by one of its corners in a steady breeze and tie the four bands from the laths of the kite to a string in such a way that the plane of the kite is at right angles to the main string which is exactly in the direction of the wind (Fig. 45). Attach a spring balance S (dynamometer) to the string and, steadying the kite, read the pull (F) registered by the dynamometer. Measure the area (A) of the kite. Then the *whole pressure* or *thrust* of the air is shown by the force (F) distributed over the whole area (A) of the kite.

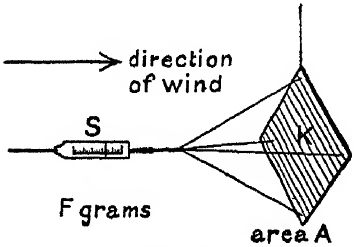


Fig. 45.

Then the **pressure on unit area** $= \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$.

If the pull on the dynamometer $= 16$ pounds,
and the area of the kite $= 4$ sq. ft. $= 576$ square inches,
then the pressure $= \frac{16 \text{ pounds}}{576 \text{ sq. ins.}} = \frac{1}{36}$ *pound per square inch.*

The **pressure** due to a **column of liquid** may be measured as follows:

Ex. ii. A gas cylinder (C), the closed end of which has been cut off, is clamped vertically. A ground glass plate (P) is held firmly pressed against

the lower ground rim of the cylinder by means of a string attached to a spring balance (S) which is pulled tightly (Fig. 46). Pour *water* into the cylinder and note the height of the column (h cm.). Then gradually lessen the force supporting the plate by lowering the dynamometer. Note the pressure when the support gives way and the water escapes. Repeat several times, always filling the cylinder with water to the same level. Subtract the weight of the plate from the average of your results. Let F = the supporting force. Measure the internal diameter of the cylinder and calculate the *area of cross-section* (A sq. cm.). Then the pressure on a plate of A sq. cms. is F grams, *i.e.* the **pressure** $= \frac{F}{A}$ **grams per square centimetre.** This result $\left(\frac{F \text{ grams}}{A \text{ sq. cms.}}\right)$ clearly gives us the pressure when the area of cross-section of the cylinder is reduced to 1 *sq. cm.* and, since the height of the cylinder of water $= h$ cm., the number of c.c. of water pressing on each sq. cm. $= h$ c.c., but 1 c.c. of water weighs 1 gram.,

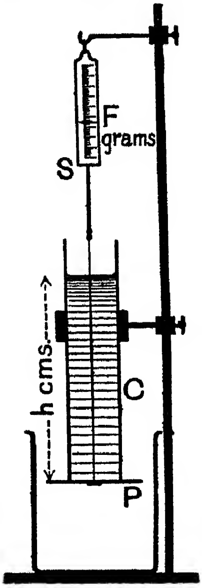


Fig. 46.

$\therefore$ the pressure due to a column of water of h cm. vertical height $= h$ grams per square centimetre, and we find that in a liquid the **pressure is proportional to the depth.**

Example Observations.

Weight of plate	= 18 grams.
Average pull on dynamometer	= 750 grams.
Force necessary to support water (F)	= 750 − 18 = 732 grams.
Depth of water (h)	= 30 cm.
Internal diameter of cylinder	= 5·6 cm.

$\therefore$ Area of cross-section $= \pi r^2 = 24{\cdot}64$ sq. cm.

$$\therefore \text{ Pressure} = \frac{732 \text{ grams}}{24{\cdot}64 \text{ sq. cm.}} = 29{\cdot}7 \text{ grams per sq. cm.}^{[1]}$$

[1] **Percentage Error.** If we assume that in water the pressure in grams per square centimetre at a depth h cm. $= h$ grams, then the pressure at depth 30 cm. = 30 grams per sq. cm.

By experiment we have found the pressure = 29·7 grams per sq. cm.

$\therefore$ the experimental error $= 30 - 29{\cdot}7 = {\cdot}3$ in the correct result which is 30,

$$\therefore \text{ the } \textit{percentage error} = \frac{{\cdot}3 \times 100}{30} = 1\ \%.$$

Exp. A graphic method of showing that in a liquid the pressure increases as the depth increases is shown in Fig. 47, where a tall vessel is

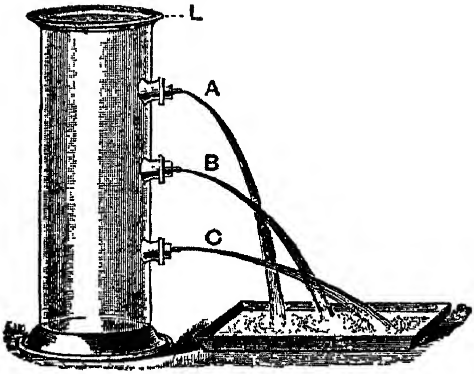


Fig. 47.

furnished with three outlets at different levels. If the outlets are of the same bore (cross-section), more water will flow from a lower than from an upper level in a given time. A tap above the vessel should give a sufficient supply of water to keep the *head of water* at level L constant. Collect and measure the volume of water which flows from each tap in 15 secs.

Pressure at depth h in a liquid of density D.

Since, by definition, 1 c.c. of the liquid weighs D grams, the weight of a column of liquid of h cm. vertical height and 1 square cm. cross-section $= h \times D$ grams.

$\therefore$ pressure at depth $h =$ **$h \times D$ grams per square cm.**

41. Fluids (Liquids and Gases) transmit pressure equally in all directions.

(1) If we place our hands some distance apart on a partially inflated bicycle tyre and press gently with the fingers of one hand we can feel the pressure transmitted through the air in the tube to the other hand.

(2) If we squeeze an india-rubber ball which we have filled with water through a single hole by suction, we know that the same amount of pressure applied at any part of the ball towards

its centre produces the same effect in squirting water out of the hole, no matter in what direction the hole is pointing. We can imagine the ball fitted with outlet tubes of equal cross-section (1 sq. cm.) in which move frictionless pistons *P*, *Q*, *R* (Fig. 48). If an inward pressure of *F* grams is applied at *P* there will be transmitted to all parts of the cover a pressure of *F* grams per square centimetre and consequently the pistons *Q* and *R* will each be driven out with a force of *F* grams. On this principle hydraulic presses and lifts are constructed (see § 66).

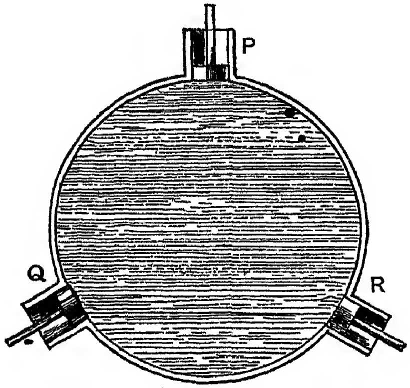


Fig. 48.

42. To show experimentally that in a liquid—
(*a*) **the pressure is the same at equal levels,** and
(*b*) **that the pressure is the same in all directions.**

Exp. In § 33, the statement was made that in a liquid the pressure is proportional to the depth and since we assume the surface to be level (*i.e.* in a plane at right angles to the direction of the plumb-line) it follows that the pressure will be the same at equal levels. Pour water into a large beaker capable of holding several litres and mark the level *LL*, with a chalk line or with bands of paper, when the depth is about 2 inches (Fig. 49). Fill up the beaker to a depth of about 10 inches. Over a funnel (*F*), bent in the form of an L, stretch and tie tightly a piece of thin india-rubber; mark the centre of the rubber circle with a spot of ink or dye. Connect the open end of the funnel to a U-tube, in the bend of which is placed some coloured water. Lower the rubber-closed funnel into the beaker and note that the pressure on the rubber is *transmitted* through the air in

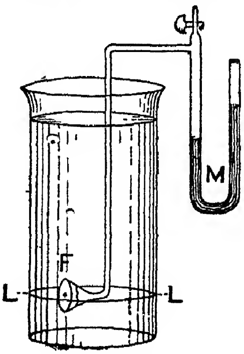


Fig. 49.

the U-tube and that the coloured water is depressed on one side and rises equally on the other, and that the deeper the funnel is lowered the greater is the amount of pressure recorded. This U-tube is a simple form of *pressure gauge* or *manometer M*.

Move the funnel *pointing it in various directions so that its centre is at different positions* in the level *LL* marked by the chalk or paper line. It will be seen that if these conditions are carefully maintained, the pressure as shown by the manometer does not vary.

The pressure at a point is measured by the thrust on a square centimetre having the point at its centre.

The shape of the vessel does not affect the pressure at any particular depth.

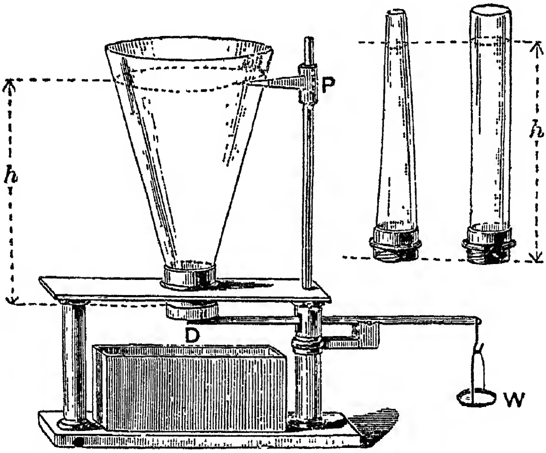


Fig. 50.

Exp. The three variously shaped vessels shown in Fig. 50 have openings at the bottom of *equal area of cross-section.* The edge of the opening is carefully ground and a plate attached to one arm of a lever is pressed against the opening by adding weights *W* to the scale-pan. Water is run into the vessel until the supporting plate yields and the water escapes. The depth of water (h) is noted and the experiment is repeated when another of the vessels is placed in position against the plate. Water to the same depth (h) is added before the plate moves from the rim and the scale-pan is raised, thus showing that the pressure on a definite area of the base depends on the depth of the liquid and not on the shape of the vessel.

43. Revision Experiment. (A.)

To show that the upward pressure (or thrust) at any depth in a liquid is equal to the downward pressure.

(1) Procure two or three lamp chimneys of entirely differing shapes. (The lower edge should be ground flat.) In Fig. 51 *a* a cylindrical one (*C*) is shown. *P* is a piece of mill-board[1], which, if it can be obtained, should be of the same density as water. The mill-board is wetted and held tightly against *C* by a string passing through its centre. Lower the apparatus into water. The mill-board remains in position *pressed upwards* when the string is loosened. Carefully pour water into chimney and note that the mill-board comes away when the water reaches *L*, the level of the surrounding liquid.

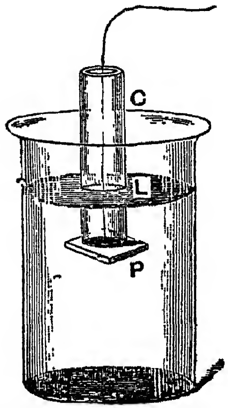


Fig. 51 *a*.

(2) Repeat the experiment, substituting a chimney of different shape, and lowering to various depths.

(3) Repeat the experiment, holding the chimneys in positions other than the vertical.

Draw your conclusions and write them out in order.

Revision Experiment. (B.)

To find **the relation between** (*a*) **Pressure,** (*b*) **Depth and** (*c*) **Area** over which pressure is exerted in a liquid[2]

[1] A flat disc of box-wood, of the same density as water, serves the purpose.

[2] In this Exp. it is assumed that when a cylinder *floats* vertically in a liquid, the pressure exerted by the liquid upwards on the base (upthrust) equals the weight of the floating body. For exercises on this Exp. see Examples on Chap. VII.

Exp. i. Flatten the bottom of a long test-tube by softening the rounded part in a blowpipe flame and pressing on an iron plate. Put a slip of mm. squared paper, marked off in centimetres measured from the outside of the bottom of the tube, into the tube, which must be corked (Fig. 51 *b*). Load the tube with sand or shot until it will float vertically in a jar of water. Note the position of the water-level by means of the squared paper scale and measure h_1. Remove the tube, dry it and weigh it with its contents (w_1). Add more sand or shot to sink the tube to a lower level, note h_2, and weigh again (w_2).

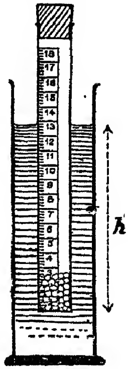


Fig. 51 *b*.

Find the ratio $\frac{w_1}{h_1}$ and $\frac{w_2}{h_2}$,

i.e. the relation between weights (pressure of water at different depths) and the depths.

***Exp.** ii. Prepare and load a boiling tube similarly, until it floats with *the same lengths* immersed as in Exp. i. Dry and weigh as before. Measure the diameters of the two tubes, calculate the area of cross-section of each, and find the relation between weights and areas, *i.e.* the ratio $\frac{W}{A}$.

State your deductions from each experiment.

44. Pressure in Liquids at rest. (*Revision and memoranda.*)

1. Density being mass per unit volume and weight being proportional to mass, density is a measure of weight per unit volume.

2. The free surface of a liquid is level (*i.e.* at right angles to the plumb line).

3. The pressure at a point is measured by the thrust on a sq. cm. having the point as centre.

4. The pressure is proportional to depth beneath the surface and is therefore the same at the same horizontal levels. In a liquid of density D grams per c.c. and at depth h, the pressure $= h \times D$ grams per sq. cm.

5. The pressure at a point is the same in all directions, consequently at any point to every pressure there must be an equal but opposite pressure, for otherwise the liquid would move.

6. Fluids transmit pressure equally in all directions.

45. To find the Relative Density of Liquids by "Balancing columns"—"U-tube method."

***Exp. i. To find the density of a salt solution.** Balance a column of the solution with a column of water as follows: Bend 2 feet of $\frac{3}{8}''$ glass tubing at its middle point in the form of a U (*Exp. Chem.* § 3). Fill the bend with mercury to about 1″ in depth and clamp the tube vertically. Pour salt solution into the right-hand arm S (Fig. 52) and water into the left-hand arm, *a little at a time*, until the arms are nearly full and the *mercury is at the same level* $L_1 L_2$ on both sides. Measure[1] the vertical heights of the two columns. For instance, suppose that—

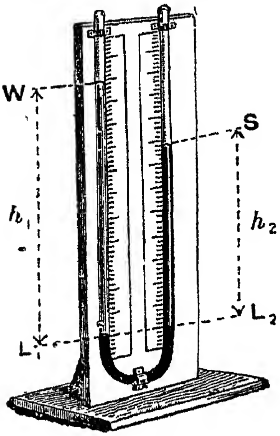


Fig. 52.

Height of water column h_1 $= 18{\cdot}1$ cm.,
Height of salt solution column $h_2 = 15{\cdot}2$ cm.

Let D_1 = density of water
and D_2 = density of salt solution.

Then

the pressure at $L_1 = h_1 \times D_1$
$= 18{\cdot}1 \times 1$ grams per sq. cm.,

and the pressure at $L_2 = h_2 \times D_2 = 15{\cdot}2 \times D_2$ grams per sq. cm.,
but the pressure at L_1 = pressure at L_2 ($L_1 L_2$ being level).

$$\therefore\ D_2 = \frac{18{\cdot}1}{15{\cdot}2} = \mathbf{1{\cdot}19\ grams\ per\ c.c.}$$

$$\text{N.B.}\quad h_1 \times D_1 = h_2 \times D_2,$$

$$\therefore\ \frac{D_1}{D_2} = \frac{h_2}{h_1},$$

or, in words,—*the densities* of the two liquids *are inversely proportional to the heights of the columns* which balance each other.

***Exp. ii. Find the relative density of two liquids which do not mix.** Use the same method and apparatus to find the density of turpentine relative to that of water. In this case mercury may be dispensed with. Half fill the U-tube with water and then carefully pour turpentine into one side. *Measure* the vertical heights of the columns *from the level where the two liquids meet.* Below this level of separation the water, which is the denser liquid, acts the part of a balance just as the mercury did in Exp. i.

[1] See *Exp. Chem.*, Fig. 9, § 8, on "Parallax Error."

Examples VII.

1. A test-tube loaded with shot weighs 20 gm. When floated in water it sinks to a depth of 10 cm. If two more grams of shot are added, to what depth will it sink?

2. A loaded test-tube weighing 20·44 gm. floats in water with 11·2 cm. below the surface. What extra weight will be needed to sink it 12 cm.?

3. A test-tube of diameter 1·6 cm. and a boiling-tube of diameter 2·2 cm. are loaded with sand till they float vertically with the same length immersed in water. If the weight of the test-tube is 20·8 gm., what does the boiling tube weigh?

4. A test-tube and boiling-tube weighing 16 gm. and 36 gm. respectively sink to the same depth in water. If the diameter of the boiling-tube is 2·4 cm., find diameter of test-tube.

5. What is the pressure per sq. cm. at the base of a column of mercury 76 cm. high (density of mercury = 13·6 gm. per c.c.)?

6. Calculate the "thrust" (total pressure) on the bottom of a tank full of water, 6 dm. long, 40 cm. wide and 40 cm. deep. What will be the pressure *at any point* in the base?

7. If the town water reservoir is 600 ft. above sea-level, find the pressure per sq. in. in a pipe at the top of a building 24 ft. above sea-level.

8. Some mercury is poured into a U-tube: water is then poured into one limb till it measures 34 cm. How high will the mercury in the other limb stand above the common surface?

9. If the density of sea-water is 1·025 gm. per c.c., what is the pressure per sq. cm. at a depth of 680 metres in the sea? At what depth in mercury would the pressure be the same?

10. What is the height of a building if the pressure at taps on ground floor and top floor is 30 lbs. and 15 lbs. per sq. in. respectively?

11. Water is poured into a U-tube and olive oil added. The height of the oil above the table = 19 cm., that of the water = 17·65 cm.: the common surface 4 cm. Calculate the relative density of oil.

12. The thrust on the bottom of a beaker (diameter 7 cm.) when full of mercury is 5·236 kgm. What is the height of the beaker?

13. Methylated spirit (density 0·816 gm. per c.c.) is poured into a U-tube containing mercury until the latter stands 3 cm. above the common surface. What is the length of the spirit column?

CHAPTER VIII.

PRINCIPLE OF ARCHIMEDES.

46. The Principle of Archimedes.

We are well acquainted with the fact that when we are bathing the water buoys us up. In learning to swim very little support is required under the chin or arms to keep our heads above water. We also know that the more we are immersed the less effort is required to support us, the water exerting an upward force which almost counteracts our weight. These facts were observed about 200 B.C. by a philosopher of Syracuse named Archimedes. The principle named after him is as follows—**When a body is wholly or partially immersed in a fluid, it loses weight by the weight of fluid displaced,** or in other words **there is an upthrust on the body equal to the weight of the fluid displaced.**

A little thought will convince us that this statement is true.

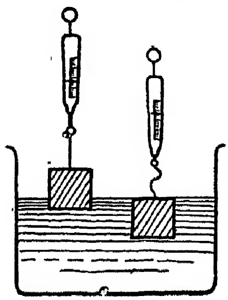


Fig. 53.

Imagine that we have a *magic* cubic centimetre box with walls so thin that they occupy no space and so light that they weigh nothing. Imagine that we fill this box with water and tie it by a weightless string to a spring balance. The balance will register the weight of 1 c.c. of water, viz. 1 gram. Into a bowl of water lower the box until one quarter of its volume is under the surface (Fig. 53): this one quarter, weighing $\frac{1}{4}$ gram, becomes

part of the water in the bowl except that it is separated from it by a weightless partition of no thickness. The balance will therefore register $\frac{1}{4}$ gram less, or in other words the boxed up water has *lost weight by the weight of water displaced.* Continue to lower the box until it is quite immersed. The balance will now register *zero*, for the whole gram of enclosed water has become part of the water in the bowl except that it is separated from it by the weightless box. Next let us fit into the imaginary box 1 c.c. of lead which weighs 11·3 grams. Lower the leaden cubic centimetre into water. The lead continues to lose weight until it is completely immersed, when again 1 c.c. of water (1 gram) is displaced and the spring balance registers 10·3 grams.

47. Experimental Proof of the Principle of Archimedes.

Exp. The following is often called the "cylinder and bucket" experiment (Fig. 54). A cylinder *C*, *fitting exactly into a bucket B*, is suspended to one arm of a balance and counterpoised. The cylinder is then placed in a beaker, the latter being supported on a shelf placed over the scale-pan. Water is then carefully poured into a beaker until it is about full. The balance is disturbed as part of the weight of the cylinder is supported by the water. Water is now added to the bucket until the balance again swings evenly: it is then found that the same volume of water has been poured into the bucket as the cylinder is displacing in the beaker. Fill the beaker nearly full of water and continue to add water to the bucket until a balance is again obtained: the bucket will now be found to be exactly full, and, as its internal volume equals exactly the volume of the cylinder, it is evident that *on being placed in water the cylinder has lost in weight by the weight of the volume of water displaced.*

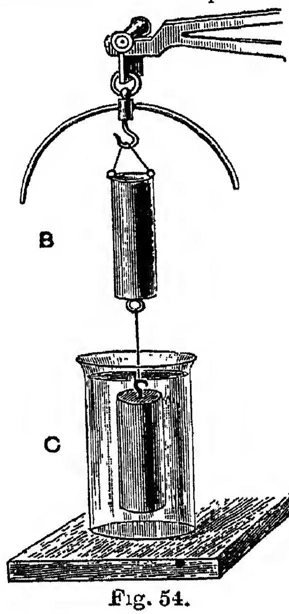


Fig. 54.

48. To find the Relative Density of a Solid by the Principle of Archimedes.

***Exp. i. To find the Relative Density of Copper.** Suspend a copper cylinder C by a piece of fine silk to one arm of a balance (Fig. 55).

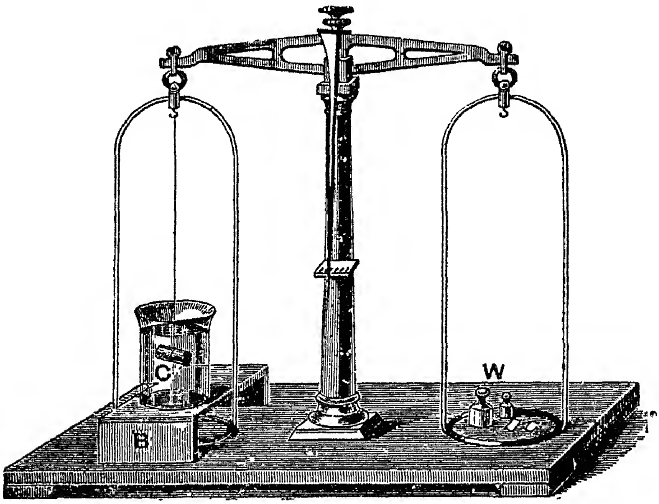


Fig. 55.

(1) Weigh the copper cylinder $= 64{\cdot}29$ grams.

Place the cylinder in a beaker of water, the beaker being supported on a bridge B.

(2) Weigh the copper cylinder (in water) $= 57{\cdot}11$ grams.

The loss of weight, on weighing in water, $= 7{\cdot}18$ grams.

∴ by the Principle of Archimedes,

the weight of water displaced $= 7{\cdot}18$ grams.

∴ the weight of water equal in vol. to the cylinder $= 7{\cdot}18$ grams.

$$\text{The Rel. Density of Copper} = \frac{\text{Wt. of copper cylinder}}{\text{Wt. of an equal volume of water}}$$

$$= \frac{64{\cdot}29 \text{ grams}}{7{\cdot}18 \text{ grams}} = \mathbf{8{\cdot}95};$$

hence, the rule:

$$\textbf{Relative Density of a Solid} = \frac{\textbf{Weight of solid (in air)}}{\textbf{Loss of weight in water}}.$$

***Exp.** ii. Repeat the experiment, using a *spring balance.*

Further Practical Exercises. Find the density of Iron (cylinder), Aluminium (cylinder), and Glass (a stopper). (Cf. § 31.)

49. To find the Relative Density of a Liquid by the Principle of Archimedes.

***Exp. To find the Relative Density of Methylated Spirit.**

$$\text{Rel. Density of Spirit} = \frac{\text{Wt. of a given volume of spirit}}{\text{Wt. of same volume of water}} \quad \text{(by Definition).}$$

Weigh a metal cylinder (1) in air, (2) in methylated spirit, (3) in water, then,

$$\text{Rel. Density of Spirit} = \frac{\text{Loss of wt. of a solid in spirit}}{\text{Loss of wt. of same solid in water}} \quad \text{(by Archimedes).}$$

$$\text{Rel. Density of Spirit} = \frac{\text{Wt. in air} - \text{wt. in spirit}}{\text{Wt. in air} - \text{wt. in water}}.$$

For example, take the following observations:

(1) Wt. of a metal cylinder in air $= 64{\cdot}29$ grams.

(2) Wt. of the *same* cylinder in spirit $= 58{\cdot}55$ grams.

(3) Wt. of the *same* cylinder in water $= 57{\cdot}11$ grams.

$$\therefore \text{Rel. Density of Spirit} = \frac{64{\cdot}29 - 58{\cdot}55}{64{\cdot}29 - 57{\cdot}11} = \frac{5{\cdot}74 \text{ grams}}{7{\cdot}18 \text{ grams}} = \mathbf{0{\cdot}8}.$$

50. To find the Relative Density of a Solid which floats on water.

***Exp. To find the Relative Density of Cork.** Weigh a metal cylinder, round which a piece of thin wire is wound, in water as in Exp. i, § 48, Fig. 55.

(1) Weight of cylinder + wire (in *water*) (Fig. 55) $= 67{\cdot}54$ grams.

Place the cork in the balance-pan (dry) and weigh again.

(2) Weight of cylinder + wire (in *water*) + cork (in *air*) $= 67{\cdot}99$ grams.

$\therefore$ Weight of cork $= (2) - (1)$ $= 0{\cdot}45$ grams.

By means of the wire, tie the cork to the cylinder, and weigh both cylinder and cork in water: the loss of weight = weight of water displaced by the cork = weight of water equal in volume to the cork.

(3) Weight of cylinder + wire + cork (*all* in *water*) = 65·74 grams.

∴ Weight of water displaced by the cork = (2) − (3) = 2·25 grams.

$$\therefore \text{ Rel. Density of Cork} = \frac{\text{Wt. of cork}}{\text{Wt. of equal vol. of water}} = \frac{0{\cdot}45}{2{\cdot}25} = 0{\cdot}2.$$

51. To show that when a solid is immersed there is a downthrust on the bottom of the vessel equal to the upthrust of the liquid on the solid[1]

(1) Weigh a beaker containing water = 82·67 grams.

(2) Suspend the same copper cylinder as was used in § 48, Exp. i, in the beaker (Fig. 56) and weigh again = 89·85 grams.

There is an *increase* of weight observed = 7·18 grams,

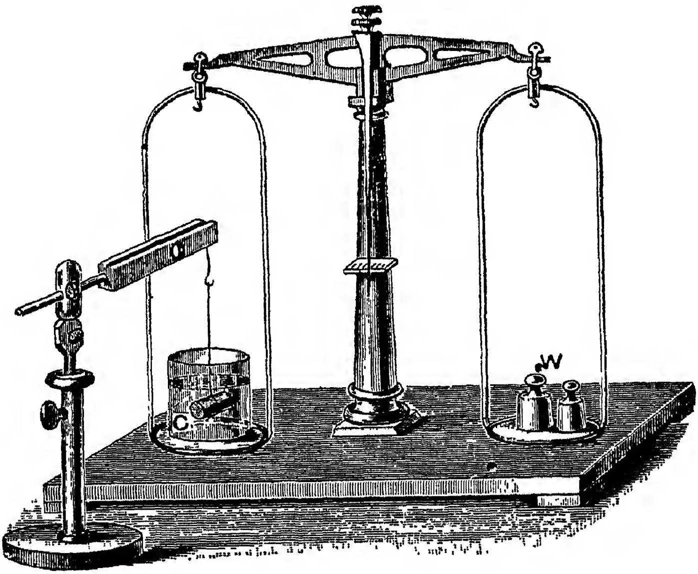


Fig. 56.

[1] This experiment is a good illustration of Newton's Third Law—"To every action there is an equal and contrary reaction."

which also equals the *loss* of weight recorded on weighing the cylinder in water (§ 48, Exp. i). There is therefore a downthrust on the bottom of the vessel equal to the weight of water displaced, *i.e.* equal to the upthrust of the liquid on the solid immersed. This result was to be expected for by suspending the solid in the water we have *raised the level of the water* in the beaker by the volume of the solid. The same result would have been obtained if, instead of suspending the solid, we had raised the surface of the water to the new level by addition of water equal in volume to that of the solid.

***Revision Experiment. Find the Relative Density of Methylated Spirit** by the method of the last experiment (downthrust method). Find the downthrust (1) in spirit, (2) in water, and explain fully how the relative densities of the two liquids may be obtained.

*Practical Exercises in indirect measurement.

1. Find the *diameter* of a piece of wire by finding the volume of a known length by a displacement method and hence obtain the *area* of cross-section. Confirm your result by using the screw-gauge (§ 6).

2. Find the *length* of a coil of wire, without unwinding it.

3. Find the average *internal diameter of a glass tube,* given enough mercury (density 13·6) to fill the tube, a beaker, cm. scale, balance and weights.

Examples VIII (Archimedes' Principle).

1. A piece of copper weighs 40·05 gm. in air and 35·55 gm. in water. Find the relative density of copper.

2. If a piece of brass (density 8·4 gm. per c.c.) weighs 68·04 gm. in air, what will it weigh in water?

3. Find the density of a piece of marble, volume 6·55 c.c., which weighs 17·685 gm.

4. If a man can only just lift 144 kgm. of iron (density 7·2 gm. per c.c.) in water, what weight can he lift in air?

5. An article weighs 12·5 gm. in air, 8·5 gm. in methylated spirit of density 0·8 gm. per c.c. Calculate density of the article.

6. Find the relative density of a piece of silver which weighs 34·65 gm. in air, 31·35 gm. in water.

7. A piece of iron (density 7·2 gm. per c.c.) weighs 47·16 gm. in air. What will it weigh in water?

8. What will a glass cube, side 4 cm. long, weigh in air and in water if the density of glass is 2·5 gm. per c.c.?

9. A marble weighs 4·5 gm. in water and 2·1 gm. in sulphuric acid of density 1·8 gm. per c.c. What is the volume of the marble?

10. What weight of marble (relative density 2·7) can a boy support in water if 119 lbs. is the greatest weight he can lift in air?

11. A piece of tin, volume 11·5 c.c., weighs 83·95 gm. Calculate its density.

12. A piece of rock salt weighs 9·45 gm. in air and 4·41 gm. in brine (density 1·12 gm. per c.c.). What is the density of rock salt?

13. A lump of salt of density 2·1 gm. weighs 16·8 gm. in air. What will it weigh in methylated spirit of density 0·82 gm. per c.c.?

14. An ebony cylinder of height 5 cm. weighs 9·24 gm. in air and 1·54 gm. in water. What is its diameter?

CHAPTER IX.

FLOATING BODIES AND HYDROMETERS.

52. Reasons for floating or sinking.

In Fig. 57 a body is shown immersed in a liquid.

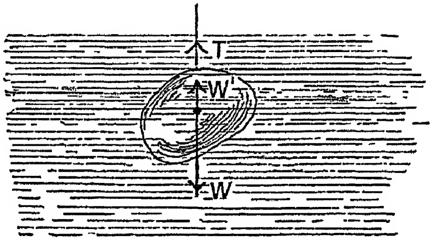


Fig. 57.

Let W represent the weight of the body,

and W' the upthrust due to the displaced liquid.

These two forces act in opposite directions in the same straight line.

(1) If $W > W'$, the body will sink, unless it is supported by a string. The pull on the string, *i.e.* the tension T, $= W - W'$.

(2) If $W = W'$, the body will remain wherever it is placed in the liquid, the density of the solid being equal to that of the liquid.

(3) If $W < W'$, the body will rise to the surface and float: the volume of the body under the surface then displaces a weight of water equal to the weight of the body, *i.e.*

Weight of a floating body = weight of liquid displaced.

***53.** (1) **To find the Density of Wood by Flotation.**

Let D be the **Density** of a smooth *rectangular* block of wood (Fig. 58). Smear the block with vaseline and rub it dry.

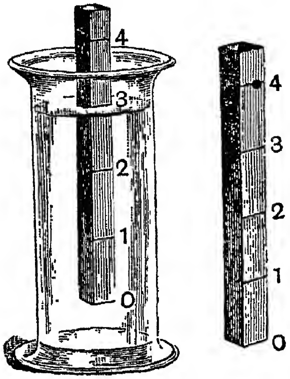


Fig. 58.

Since the block is rectangular its area of cross-section is constant $= A$ sq. cm.

Let

the length of the block = (say) 45 cm., then

the volume of the block $= A \times 45$ c.c., and

the weight of the block

$$= A \times 45 \times D \text{ grams} \ldots (1)$$

Float the block in water, gently supporting it vertically.

Measure the **depth** to which it sinks = (say) 30 cm.

Then the volume of water displaced $= A \times 30$ c.c.

$\therefore$ the weight of the block $= A \times 30 \times d_w$ grams ....(2),

where $d_w =$ density of water $= 1$,

but $(1) = (2)$,

$$\therefore\ A \times 45 \times D = A \times 30 \times 1 \quad \ldots\ldots\ldots\ldots\ldots (3),$$

$$\therefore\ D = \tfrac{30}{45} = 0 \cdot \dot{6},$$

or, in words,

$$\text{the } \textit{density of the wood} = \frac{\text{depth to which the block sinks in water}}{\text{total length of rectangular block}}$$

*(2) **To find the Density of a Liquid by the Flotation Method.**

Let d_s be the **Density** of the liquid (say *Methylated Spirit*). Float the same block as was used in the above experiment, and measure the vertical **depth** to which it sinks = (say) **37 cm.,**

then the weight of the block $= A \times 37 \times d_s$ grams,

but by (2) „ „ „ $= A \times 30 \times d_w$.

$$\therefore \quad A \times 37 \times d_s = A \times 30 \times d_w \quad \text{......................} (4),$$

$$\therefore \quad 37 \times d_s = \quad 30 \times d_w = 30 \times 1 \text{..............} (5),$$

$$\therefore \text{ the Density of Methylated Spirit} = d_s = \tfrac{30}{37} = 0{\cdot}81.$$

Let us put into words Equation (5), remembering that we are using a block of uniform cross-section and that we are floating it first in spirit and then in water. Equation (5) then reads:

depth of sinking in spirit × density of spirit
= depth of sinking in water × density of water,

$$\therefore \frac{\text{density of spirit}}{\text{density of water}} = \frac{\text{depth of sinking in water}}{\text{depth of sinking in spirit}},$$

i.e. the densities of the two liquids are inversely proportional to the depths to which a block of uniform cross-section will sink in those liquids.

54. A **hydrometer** is a graduated float used for finding the relative densities of liquids by comparing the depths to which the instrument sinks in the various liquids.

The simplest form of hydrometer has already been constructed in Exp. B, § 43 (see Fig. 51 *b*).

***Exp.** i. **Float the loaded test-tube** (Fig. 51 *b*) in various liquids (water, salt solution, methylated spirit, petrol, glycerine) and note the depths to which it sinks. Find the *relative density* of each liquid by dividing the depth to which the hydrometer sinks in water by the depth to which it sinks in the liquid. (Cf. § 53 (2).)

***Exp.** ii. Confirm your results in Exp. i by using the **common hydrometer.**

The **common hydrometer** (Fig. 59) is constructed on the same principle. It is made of glass and consists of a bulb (*B*) containing mercury, a float (*F*) containing air and a stem (*S*) which carries a graduated scale. When the hydrometer floats in the liquid the *specific gravity* may be read on the scale by noting the graduation which is level with the surface. Since the cross-section of the instrument varies the graduations are not equal.

Fig. 60 shows the same hydrometer floating in water and in alcohol.

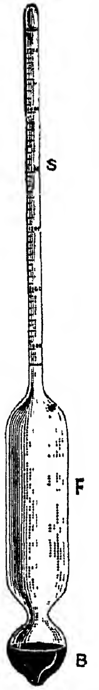


Fig. 59.

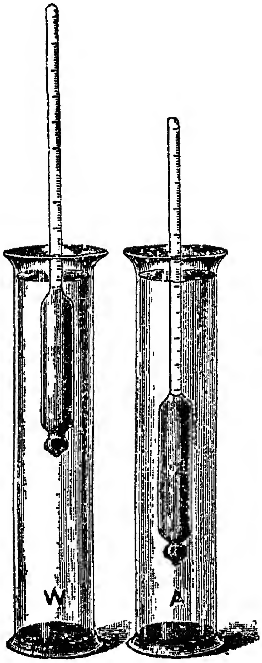


Fig. 60.

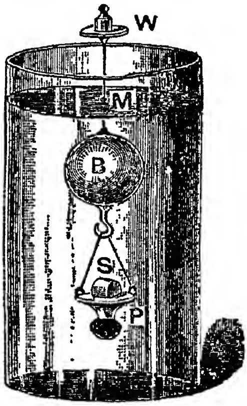


Fig. 61 *a*.

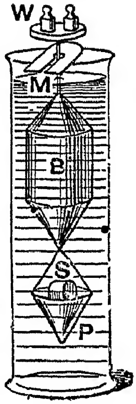


Fig. 61 *b*.

55. Nicholson's Hydrometer (Figs. 61 *a* and *b*) consists of a hollow cylinder or bulb (*B*) which supports a heavy pan (*P*) below and a fine stem above, on which is a mark (*M*), bearing a lighter pan (*W*).

***Exp. i. To find the Rel. Density of a Solid** (say a *stone*). Float the Nicholson's hydrometer in sufficient water to cover it about ½ inch above *M*.

Always adjust the weights until *M* is in the surface of the water.

(1) Add weights to *W* = (say) 12 grams.

(2) Put the *stone* and *weights* in *W*. The *weights* alone = (say) 3 grams.

∴ Weight of *stone* = 9 grams.

Remove the weights, lift the hydrometer and place the stone (S) in the lower pan (P).

(3) Add weights to W until M is again in the surface = (say) 6·39 grams.

∴ the upthrust = weight of water displaced by the stone
$= 6{\cdot}39 - 3 = 3{\cdot}39$ grams.

$$\therefore \text{ the Rel. Density of the stone} = \frac{9 \text{ grams}}{3{\cdot}39 \text{ grams}} = 2{\cdot}65.$$

If the solid is less dense than water (say a cork), a piece of fine wire for tying the cork to P should be attached to P throughout the experiment.

***Exp. ii. To find the Rel. Density of a Liquid** (say *salt solution*) weigh the Nicholson's hydrometer and add weights to W to sink the instrument to the mark M when it is floating (1) in salt solution, (2) in water. Let the hydrometer weigh 200 grams.

(1) Weights added to W when hydrometer is sunk to mark M in salt solution = 54·5 grams.

∴ Weight of salt solution displaced $= 200 + 54{\cdot}5$ grams.

(2) Weights added to W when hydrometer is sunk to mark M in water = 12 grams.

∴ Weight of an equal vol. of water $= 200 + 12$ grams.

$$\therefore \text{ Rel. Density of salt solution} = \frac{254{\cdot}5}{212} = 1{\cdot}2.$$

Twaddell's Hydrometer Scale calls for a passing reference as it is in common use in factories and works. The *hydrometers* are made very sensitive and have been adapted for use in testing the density of liquids greater than that of water; the *Scales* are so arranged that if the reading is multiplied by 5 and added to 1000, the specific gravity of the liquid is given with reference to water as 1000.

The Lactometer. An indication but not an infallible test of the purity of milk is afforded by the use of a special hydrometer which sinks to a mark on the stem in pure milk at a certain temperature.

Examples IX (Floating Bodies).

1. When a piece of elm wood of relative density 0·57 and volume 10 c.c. is floating in water, what volume will be immersed? What weight must be placed on it to just sink it?

2. A cube of white pine wood, 5 cm. side, floats in water with 2 55 cm. of each side immersed. Calculate the relative density of the wood.

3. If a piece of iron of relative density 7·6 and volume 6 8 c.c. floats in mercury of relative density 13·6, what fraction of its volume will be immersed?

4. An iceberg floats in sea water of relative density 1·025 with 500 cu. yd. above the surface. If the relative density of ice is 0 918, what is the total volume of the iceberg?

5. A loaded test-tube sinks to a depth of 12·3 cm. in water. To what depth will it sink in methylated spirit of relative density 0·82? If depth in turpentine is 14 cm., what is the relative density of turpentine?

6. A cork, relative density 0·25, is dropped into water in a graduated cylinder and causes the level to rise from 30 c.c. to 32 c.c. What is the volume of the cork?

7. What must be the volume of the chambers of a floating dock intended to support a vessel of 20,000 tons?

8. If a load of 135 tons is placed in the centre of a floating raft of length 80 ft. and width 40 ft., how much will the raft sink?

9. A loaded test-tube sinks 16·8 cm. in water, 15 cm. in brine. What is the density of the brine? How deep would it sink in milk of relative density 1·02?

10. 18·5 gm. are needed to sink Nicholson's hydrometer to the mark. With a piece of ebony in upper pan 10·1 gm., and with ebony in lower pan 17·1 gm. are required. Calculate the relative density of ebony.

11. 16·19 gm. sink Nicholson's hydrometer to the mark: with a piece of copper in upper pan 12·185 gm., with copper in lower pan 12·635 gm. are required. What is the relative density of copper?

12. When a glass stopper weighing 4 gm. and of relative density 2·5 is placed in the upper pan, 8·5 gm. are required to sink hydrometer to the mark. What weight will be needed when the glass is placed in the lower pan?

CHAPTER X.

ATMOSPHERIC PRESSURE.

56. The atmosphere is the envelope of air encircling the earth. It extends to a height of more than 100 miles. We have learnt (§ 40) that air in motion (wind) exerts pressure. We should therefore expect that air has weight. Galileo (b. 1564) proved this by showing that a copper sphere increased in weight when air was pumped into it. We can easily show that a glass globe (Fig. 62) loses weight as air is pumped out. A litre flask rendered vacuous loses 1·293 grams in weight, if originally filled with dry air at 0° C. under average atmospheric conditions of pressure.

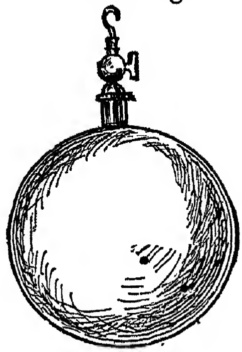


Fig. 62.

Exp. To find the weight of a litre of air.

Boil about 30 c.c. of water in a 300 c.c. round-bottomed flask, fitted with a rubber cork through which a glass exit-tube passes. Attach a piece of rubber tube and a clip to the exit-tube (Fig. 63). When the water has boiled for 2 minutes it may be assumed that all air in the flask has been displaced by steam. Close the rubber tube with the clip and *at the same time* remove the flame. When the flask is cold, *weigh it* (say 87·21 grams). Open the clip; air rushes in; weigh again (say 87·58 grams). The difference between these weights (0·37 gram) is the *weight* of the *air* entering the flask. Measure the volume of water remaining in the flask (say 28 c.c.) and also the total capacity of the flask (say 334 c.c.). The difference (306 c.c.) is the *volume of air* entering the flask. Therefore 306 c.c. of air weigh 0·37 gram.

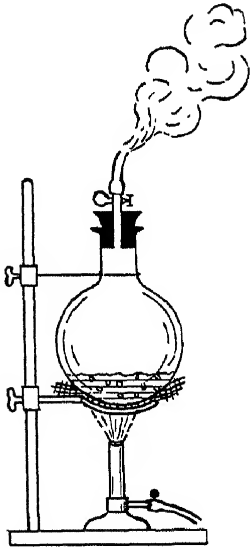


Fig. 63.

$$\therefore \text{ 1000 c.c. of air weigh } \frac{0{\cdot}37 \times 1000}{306} = 1{\cdot}21 \text{ grams}^{1}.$$

57. Air exerts pressure.

Exp. i. Tie a piece of rubber sheeting (*e.g.* football bladder) over the rim of an open cylinder, ground at one end (Fig. 64). Place the cylinder on the well-greased plate of a Tate's air pump and exhaust the contained air. As the air is removed the pressure of the atmosphere is shown by the collapse and final bursting of the rubber sheet.

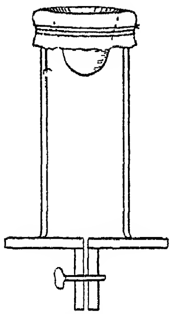


Fig. 64.

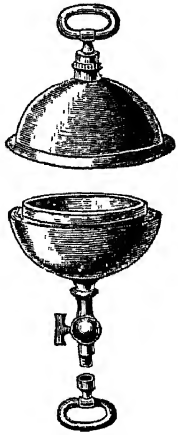


Fig. 65.

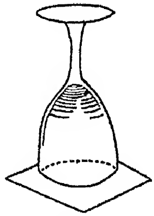


Fig. 66.

Exp. ii. **Von Guericke's (Magdeburg) Hemispheres.** This experiment was originally shown by Von Guericke at Magdeburg about 1650. Two tightly fitting hemispheres (Fig. 65) are exhausted by an air pump. The tap is turned off and a handle is screwed on to the nozzle. Great force is now required to separate the hemispheres which enclose a vacuum.

Exp. iii. **The "wine-glass" experiment** demonstrates that air presses in all directions. Fill a wine-glass with water. Place a card on the top and, pressing gently with the hand to keep the card in position, invert the glass as shown in Fig. 66. On removing the hand, the card remains pressed against the rim and the water is retained inside the wine-glass. It is evident that the pressure of air from without is greater than the pressure of water from within. It is conceivable that we might have used a cylinder of

[1] This result gives the weight of a litre of air under the laboratory conditions of temperature (15° C.) and pressure (763 mm.) at the time of the experiment.

such length that the pressure of the water inside would have been greater than the atmospheric pressure: the water would then have escaped on inverting the cylinder.

Exp. iv. Punch a round hole in the lid of a mustard canister. Select a small cork to fit the hole. Solder the lid on the canister, making the latter completely airtight. Boil a little water in the canister and when it is boiling put the cork tightly in the hole and remove the flame. Quickly condense the steam inside the tin by pouring cold water on the outside. A vacuum is formed and the pressure of the air causes the tin to collapse and crumple up.

Exp. v. An elongated U-tube about a yard in length has the end of one arm fitted with a tap. The tap is opened and mercury is poured in by the funnel on the left until the tube is half full. The mercury is at the same level on both sides (L_1), showing that the pressure is the same, both sides being open to the atmosphere. By connecting to a Bunsen's vacuum pump, air is now pumped out of the right-hand arm and consequently the pressure is gradually lessened until an almost perfect vacuum is obtained. The mercury rises on the right but falls on the side open to the atmosphere. The difference in level (L_2L_3) is measured and found to be about 30 inches or

760 mm. $= H$.

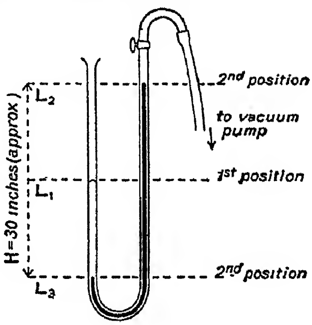


Fig. 67 *a*.

The tube is next disconnected from the vacuum pump when the mercury regains its original position. The tap being still *open* the tube is tilted (Fig. 67 *b*) until the mercury reaches the tap (Fig. 67 *c*), when the latter is immediately *closed* and the tube replaced by the vertical position. A space, a vacuum, now appears between the tap and the mercury and the difference in level of the mercury on the two sides is found to be about 30 inches as before (Fig. 67 *a*).

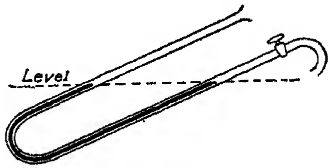


Fig. 67 *b*.

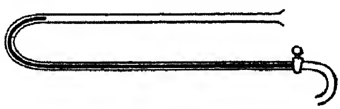


Fig. 67 *c*.

Exp. vi. (*a*) Dip the end of a tube about a yard long vertically in water and create a partial vacuum by sucking the air out at the upper end. The water rises in the tube. Explain this.

(*b*) Repeat the experiment, but dip the long tube vertically in mercury (density 13·6); it is impossible to suck the mercury up the tube more than a few inches. Explain this.

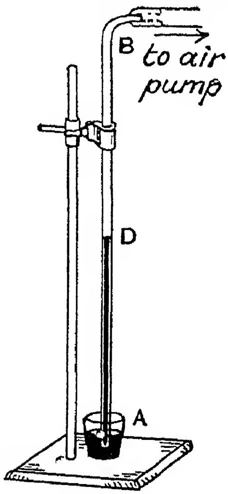


Fig. 68.

(*c*) Connect the tube to a Bunsen's vacuum pump with a piece of pressure tubing and exhaust the air from the tube (Fig. 68). The mercury rises gradually until the vertical height of the column AB = nearly 30 inches = H.

Exp. vii. (*a*) Fill a tube of about a yard in length closed at one end, with *water* (coloured). Place the thumb tightly over the open end, thus enclosing the water: invert the tube in a vertical position in a bowl of water and remove the thumb. The tube remains full of water.

(*b*) Using a similar clean tube, nearly fill it with mercury. Close it with the thumb and, by tilting, allow the bubble of air to run up and down the tube several times to remove smaller air bubbles. Next, completely fill the tube with mercury, close the end with the thumb and open under a bowl of mercury, with the tube vertical (Fig. 69). The mercury falls until a space (the **Torricellian Vacuum**) appears with its lower limit about 30 inches above the level of the mercury in the trough. Slant the tube and notice that the upper level of the mercury remains constant until there is no vacuum space in the upper part of the tube. This constitutes a mercury **barometer.** The average vertical height of the column = 760 mm. or about 30 inches.

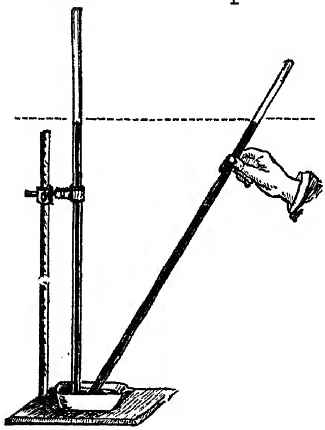


Fig. 69.

(*c*) Place the bowl of mercury and barometric tube on the plate of an air pump (Fig. 70). Place a greased bell jar over the tube and fit a perforated rubber cork (previously prepared and greased) over the tube: gradually work the cork into position until the air space over the bowl is completely closed. Now exhaust the air by the pump. Explain the reason for the gradual fall of the mercury in the tube. If a perfect vacuum could be obtained the mercury within and without the tube would be at the same level.

58. Fortin's Barometer.

In obtaining the height of the barometric column (H) the difference of level between the mercury in the trough and in the tube is measured. When the pressure is lessened the column sinks and more mercury flows into the trough, thereby raising the level in the trough. In Fortin's Barometer (Fig. 71) the scale

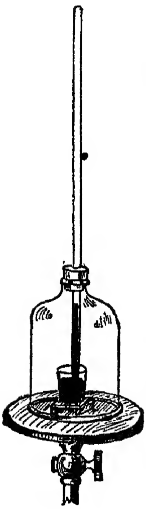


Fig. 70.

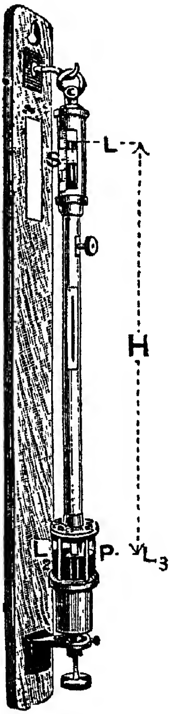


Fig. 71.

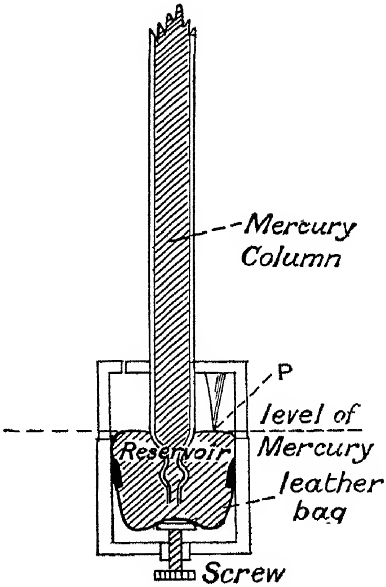


Fig. 71*b*.

(S) is attached to the tube, the zero of the scale being at the end of a fixed pin (P). The level of the mercury ($L_2 L_3$) is always adjusted to touch the point P by altering the capacity of the trough or cistern, which is fitted with a leather base moveable by means of a screw below.

Aneroid Barometer. This instrument is constructed on the principle that a thin metallic box, from which the air is partially exhausted, will expand or contract as the pressure of the air on the outside diminishes or increases. The box, "concertina-like," is cylindrical with corrugated sides; the top rises or falls with variations of the pressure. To the top is attached a lever, the end of which exaggerates the movement. From this end a minute chain passes round the axis of a pointer, the chain being kept taut by tension on a spiral spring.

General Remarks on Barometers.

The height of the barometer column measures the pressure of the atmosphere, which averages about 15 *lbs. per sq. in.*

If water were substituted for mercury in a barometer, a tube of more than 34 feet in length would be needed. For, since the density of mercury = 13·6, the weight of the atmosphere would balance a column of *water* 30 in. × 13·6 = about 34 ft. Such a column of water one square inch in section would weigh

$$\frac{62{\cdot}5 \text{ lbs.}^{1}}{1728} \times 30 \times 13{\cdot}6 = 14{\cdot}7 \text{ lbs. (approx.)}.$$

A glycerine barometer has a column of height = 27 ft.

Mercury is most useful for barometers because (*a*) its density is high (13·6); (*b*) it does not wet glass; (*c*) it does not evaporate readily; (*d*) it expands equally for equal variations of temperature.

It is evident that if we ascend or descend in the ocean of air around us there will correspondingly be less or more air above us; hence the barometer column will fall if we carry the instrument up a mountain or ascend with it in a balloon, but if we descend the mercury rises in the tube, the variation for low altitudes being approximately one inch in the height of the barometer column for a vertical rise or fall of 1000 ft.

[1] A cubic ft. of water weighs 1000 oz. = 62·5 lbs.

*59. Density of a Liquid by Hare's Apparatus.

The relative densities of two liquids may be found on a similar principle to that shown in § 45, where two columns of liquids were balanced against each other. Hare's apparatus (Fig. 72) consists of two parallel vertical tubes, connected at the top by a three-way tube fitted with a tap T, dipping into beakers containing the two liquids (say *water* and *salt* solution). The liquids are drawn up the tubes to suitable heights by suction at T. The heights of the columns (h_1 and h_2) are carefully measured from the levels L_1 and L_2 respectively. For instance, suppose that—

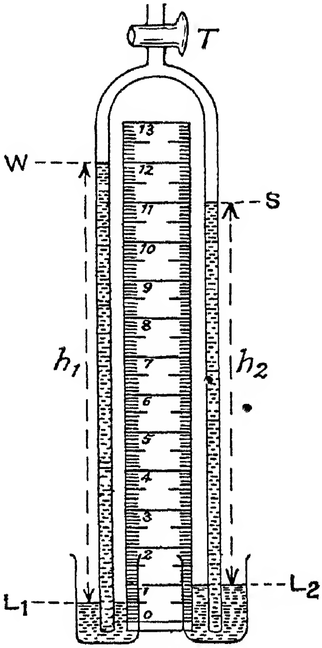


Fig. 72.

Height of column of water $h_1 = 18{\cdot}1$ cm.

Height of column of salt solution $h_2 = 15{\cdot}2$ cm.

Let D_1 = density of water = 1

and D_2 = density of salt solution.

Then, if

H = pressure (grams per sq. cm.) of the atmosphere on the liquid in each beaker,

and

p = pressure (grams per sq. cm.) of the air in tube connecting the columns,

the pressure at $L_1 = H = h_1 \times D_1$ grams per sq. cm. + p

and the pressure at $L_2 = H = h_2 \times D_2$ grams per sq. cm. + p.

$$\therefore\ h_1 \times D_1 = h_2 \times D_2,$$

$$\therefore\ 18{\cdot}1 \times 1 = 15{\cdot}2 \times D_2,$$

$$\therefore\ D_2 = \frac{18{\cdot}1}{15{\cdot}2} = 1{\cdot}19 \text{ grams per c.c.}$$

Cf. result of § 45, Exp. i. $\frac{D_1}{D_2} = \frac{h_2}{h_1}$.

60. Variation of the Density of the Air.

In § 36 we referred briefly to the constitution of a gas. The molecules of a gas are free to move, perfectly elastic and in constant motion. The gas completely fills the containing vessel. Its *density* is measured by the mass of molecules per unit volume and will vary as air is pumped into or pumped out of the vessel. At the same time the *pressure* will rise or fall, for the greater the number of molecules there are confined in a certain space the greater the number of bombardments of the molecules against the containing walls. This *variation of the density of the air with the pressure* may be shown as follows: In a bell jar connected

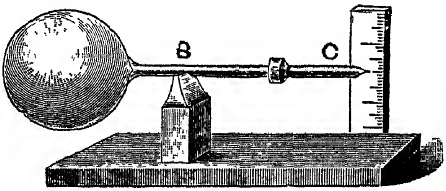


Fig. 73.

with an air pump, a closed bulb (Fig. 73), having a rod and moveable screw attached, is balanced at B. The air in the bell jar is then pumped out, its density lessening as the pressure diminishes. As the weight of the air displaced by the bulb is less, its buoyancy is also less and balance is disturbed, C rising: when air is again admitted the balance is restored as before.

The true weight of a body is its weight in vacuo, for its weight in air is less than its weight in vacuo by the weight of air displaced (see § 46). For instance the weight in air of 1000 c.c. of water at 4° C. is 1000 grams − weight of 1000 c.c. of air = 1000 − 1·2 grams (approx.).

61. Boyle's Law. The last experiment is a suitable

introduction to the subject of the variation of the *volume* of a given mass of gas with the *pressure.* If we refer to the "bicycle pump experiment" (§ 36), we shall remember that as the pressure on the air enclosed in the cylinder of the pump was increased the volume diminished, but on releasing the pressure the piston shot back, showing that the contained air has increased in volume. If we assume a knowledge of the constitution of a gas, this result was to be expected, for if we confine a given number of molecules in a smaller space there will be a consequent increase in the number of bombardments on the walls of the vessel, *i.e.* an increase of pressure. Robert Boyle of Edinburgh in 1660 experimented somewhat similarly on what he called "the spring of the air."

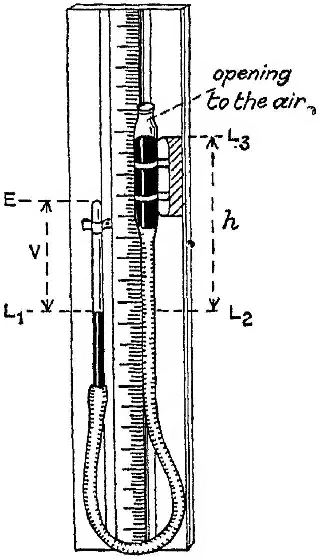


Fig. 74.

Boyle's Law.

The volume of a given mass of gas varies inversely[1] as the pressure, the temperature remaining constant.

Exp. i. To verify this law we use the apparatus shown in Fig. 74. A small quantity of air is confined in a straight tube, the end of which (E) is closed; the other end is connected with a rubber tube filled with mercury which terminates in a glass reservoir which moves vertically

[1] **When quantities vary inversely their product is constant.** Thus if (say) 48 apples are to be divided equally among boys, the greater the number of boys the less the number of apples for each boy, or, the less the number of boys the greater the number of apples. If there were 48 boys each would get 1 apple, if 24 boys each would get 2 apples, if 16 boys each would get 3 apples, if 12 boys each would get 4 apples—the product of number of apples each boy gets and number of boys is **constant** (=48 in this case); the number of apples for each boy is said to *vary inversely* as the number of boys.

along a cm. scale and is open to the air. The **volume** of the enclosed air (V) is measured along the scale (EL_1) and its **pressure** (P) is obtained by adding the difference in level (h) of the mercury in the two limbs to the atmospheric pressure H, both h and H being expressed in the same units (say cm. of mercury pressure). If the level L_3 is *above* the level L_1L_2, then h is positive, if *below* then h is negative.

The observations and results should be entered as follows:—

H = atmospheric pressure = (say) 76 cm.

Level of E on scale = (say) 55 cm.

Level L_3 on scale	Level L_1L_2 on scale	$P=H+h$ =Pressure in cm. of Mercury	V=Volume in cm. along tube	PV=constant
92	55	$76+37$	$80-55$	$113\times 25=2825$
50	45	$76+5$	$80-45$	$81\times 35=2835$
22	35	$76+(-13)$	$80-35$	$63\times 45=2835$
10	30	$76+(-20)$	$80-30$	$56\times 50=2800$

It is advisable to take the observations in the first and second columns *as quickly as possible* as the temperature may vary if there is delay: the results may be worked out afterwards.

Plot these results on squared paper, taking the pressures as ordinates. The curve obtained is called a *rectangular hyperbola.*

Exp. ii. If the apparatus described in Exp. i is not available, the following simple method will suffice for volumes measured at pressures below atmospheric pressure (H). Half fill with mercury a straight barometer tube clamped vertically (Fig. 75). Accurately measure along the tube the volume (V_1) of air between the mercury and the open end of the tube. V_1 will be at a pressure $H=P_1$. Closing the end of the tube with the thumb, invert it in a glass cylinder containing mercury; remove the thumb and measure the volume of enclosed air (V_2) and the height of the mercury column (h) when the tube is again clamped vertically. The pressure of the enclosed air $(P_2)=H-h$. It will be found that

$$P_1V_1=P_2V_2 \text{ (approximately).}$$

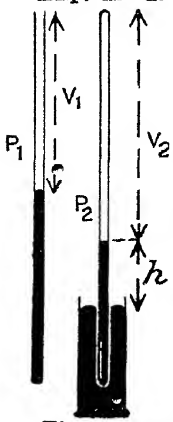


Fig. 75.

Keeping the lower end in the mercury, raise and lower the tube and take fresh readings of V and h: work out the product PV as before.

62. To find the Volume which a definite weight of a gas occupies at a changed Pressure, i.e. *to correct the volume when the pressure changes.*

We have learnt that for a given mass of gas

its Pressure × its Volume = a constant. [Boyle's Law.]

Suppose that we have 1000 c.c. (V_1) of gas at 700 mm. pressure (P_1), then the constant quantity = 700 × 1000 in this particular case.

If the pressure now changes to 800 mm. (P_2)

the changed pressure (P_2) × the new volume (V_2)

= 700 × 1000,

∴ 800 × the new Volume = 700 × 1000,

$$\therefore \text{ the new Volume} = \frac{700 \times 1000}{800} = 875 \text{ c.c.}$$

This result may be obtained directly (1) by *substituting in the formula*

$$P_1 V_1 = P_2 V_2,$$

or, it may be obtained (2) by the *unitary method*, as follows:—

At 700 mm. pressure the volume of the gas is 1000 c.c.

∴ 1 mm. " " " " 1000 × 700 c.c.

∴ 800 mm. " " " " $\frac{1000 \times 700}{800}$ = 875 c.c.

63. Revision Experiment.

To find the Density of Coal Gas relative to that of air. Weigh a dry 500 c.c. flask, fitted with a cork. Fill the flask full of coal gas by displacing the air downwards, passing a rubber tube from the gas supply vertically upwards to the top of the inverted flask. Remove the tube and quickly insert the cork, keeping the flask still inverted. Weigh the flask full of coal gas. Find the capacity of the flask. Calculate the weight of air it contains (1000 c.c. weigh 1·2 grams) and hence find the weight of the vacuous flask. By subtraction find the weight of the coal gas contained in the flask and hence calculate the weight of 1000 c.c. of coal gas.

EXAMPLES X (ATMOSPHERIC PRESSURE).

1. A 200 c.c. flask weighs 70·96 gm. when exhausted, 71·21 gm. when full of air. Calculate the density of air. What would the flask weigh if filled with oxygen (density 0·0014 gm. per c.c.)?

2. Calculate the weight of air in a room 8 m. long, 5 m. wide, 4 m. high, if the density of air is 0·00128 gm. per c.c.

3. All the air is driven out of a flask by boiling water in it. The clip is closed and the flask when cold weighs 62·72 gm. When air is admitted the weight becomes 62·875 gm. The volume of the water in the flask is 17 c.c.: total volume of flask 139 c.c. Find the weight of a litre of air.

4. A sealed glass globe of 1 litre capacity weighs 80 gm. in air of density 0·001293 gm. per c.c. What will it weigh in a vacuum?

5. A balloon contains 10 litres of hydrogen (density 0·00009 gm. per c.c.). If the density of air is 0 001293 gm. per c.c., what is the lifting power?

6. If in Hare's apparatus the height of the alcohol column is 43·3 cm. and that of the water 35·5 cm., find the relative density of alcohol.

7. How high will the water column be in Hare's apparatus if the height of a column of alcohol of density 0·82 gm. is 35 cm.?

8. A bladder containing 25 c.c. of air at a pressure of 76 cm. is placed under the receiver of an air pump and the air is withdrawn till the pressure is 40 cm. Calculate the new volume of the bladder.

9. When the mercury is level in a Boyle's tube the air in the closed limb measures 22 cm., the barometer height being 76 cm. What will it measure when the mercury is 34 cm. above the common level? What will be the height of the mercury above the common level when the air measures 11·4 cm.?

10. A certain quantity of air measures 365 c.c. under normal pressure (76 cm.). What will it occupy under (i) 73 cm. pressure, (ii) 80 cm. pressure?

CHAPTER XI.

WATER- AND AIR-PUMPS, HYDRAULIC PRESS, SIPHON, DIVING BELL.

64. A garden **syringe** (Fig. 76) is familiar to all. If the nozzle (*C*) is placed under water and the solid piston drawn out by the handle, water runs up to fill the space in the cylinder (*AB*) which would otherwise be vacuous. Knowledge of Chap. X tells us that the pressure of the air on the surface of the water in the tank forces the liquid into the cylinder. If the liquid were *mercury* instead of water we know that if the cylinder of the syringe were longer than 30 inches and were held vertically it could not be completely filled with mercury but a vacuum would appear when the level of the mercury had been raised about 30 inches above the level of the tank. Similarly it would not be possible to completely fill a syringe with water by suction if the piston could move vertically in a cylinder of more than 34 feet in length.

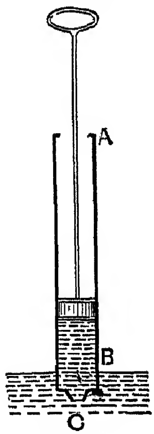


Fig. 76.

Common Suction Pump.

In Fig. 77 is shown a common suction pump which is merely a syringe with the nozzle (*D*) extended and fitted with a valve (*C*) or trap-door opening upwards; the piston (*PP*) is not solid but is

also fitted with valves (FF') opening upwards. When the piston (PP) is raised, water rises in D from the tank, the valve C preventing a back-rush of water. A few more strokes of the piston will fill the tube D, provided C is within 34 feet vertically of the level of the water D. Further pumping will raise more water into the cylinder (AB) and finally water will rush through the valves (FF') at the downstroke and be lifted and pass through E at the upstroke.

Lift Pump. If the outlet E (Fig. 77) were an upturned pipe fitted with a valve opening outwards and if the top (A) and collar of the pump were watertight, it would be possible to force the water up the tube E "by lifting." This arrangement is shown in Fig. 78.

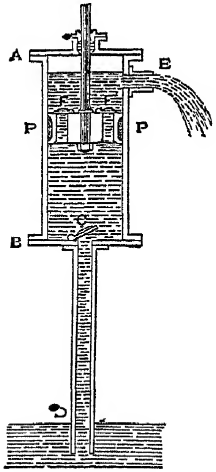


Fig. 77.

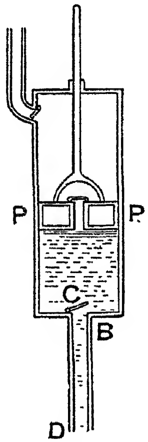


Fig. 78.

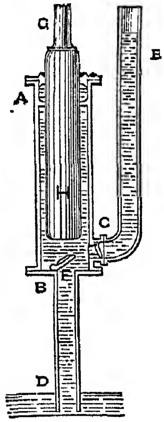


Fig. 79.

Force Pump. In Fig. 79 a similar suction pump is shown, but the piston (H) is solid (plunger) and the outlet tube E is fitted to the bottom of the cylinder. Both valves open in a direction away from the water supply. The valve F at the base of the cylinder must be within 34 feet vertically from the level of the water in the tank.

In **fire-engines** (Fig. 80) an air-dome (A) is inserted in the outlet tube where the elasticity of the compressed air maintains the pressure when the valve C is shut during the upstroke of P. Two pumps working with alternating strokes are used to keep a continuous supply of water passing into the chamber fitted with the air-dome.

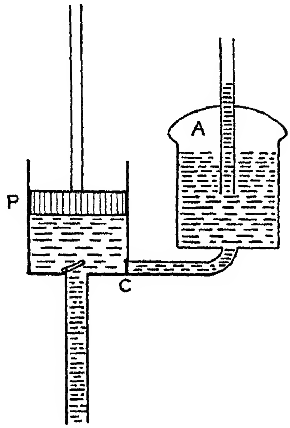


Fig. 80.

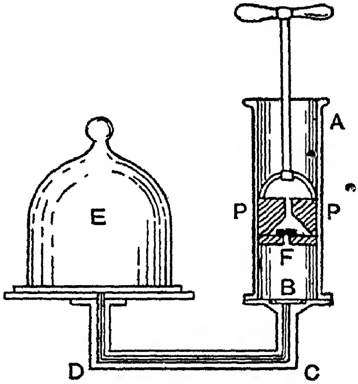


Fig. 81.

65. Air Vacuum Pump. This instrument is made on the principle of the common suction pump (Fig. 77), the vessel to be exhausted being attached to D. The arrangement is shown in Fig. 81, where A is the barrel of the pump, PP the piston, F and B the two valves both opening outwards, DC the connecting tube and E the vessel to be exhausted. The valves are of light construction and are in some instances ribbons of oiled silk lightly stretched across the end of the air passages. A perfect vacuum cannot be obtained by such an instrument because a limit is reached when the pressure of the air in the vessel is not sufficient to raise the valve.

Air Compression Pump.

Fig. 82 represents a pump suited for inflating footballs or compressing gas into cylinders. The valves at *E* and *F* both open inwards; the illustration shows the piston moving from

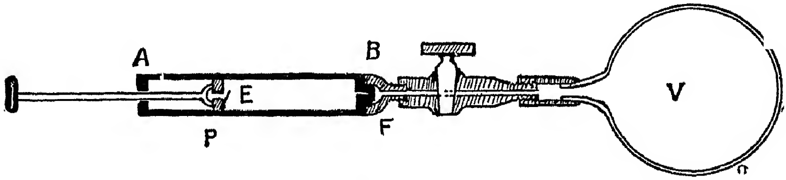


Fig. 82.

right to left, *F* being shut and *E* open; on pushing *P* to the right *E* shuts and the air contained is forced through *F* into the receiver *V*.

Sprengel's Vacuum Pump. An almost perfect vacuum may be obtained by using the apparatus shown in Fig. 83. Mercury from a reservoir *E* is allowed to flow down a tube *ABC* dipping below the surface of the mercury in the trough *G*. The rate of flow is regulated by the tap *F*. A side tube *BD*, communicating with the vessel to be exhausted, is inserted at *B* which is more than 30 inches above the level of the mercury (*G*) in the trough. If the tubes *ABC* and *BD* were first filled with mercury and the taps *F* and *D* afterwards closed, the Torricellian Vacuum would appear in the arms *AB* and *DB*. If *F* and *D* are now opened, bubbles of air are drawn through *D* by the mercury as it drops down the tube *ABC* until finally a vacuum is obtained in the vessel attached at *D*.

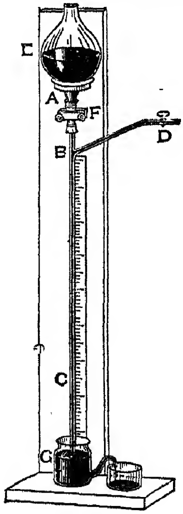


Fig. 83.

Bunsen's Vacuum Pump and the *Steam Ejector* of the vacuum brake are constructed on the principle that water or steam rushing past an opening, which points in the

same direction as the stream of water or steam is passing, causes a suction of air through the opening.

66. Hydrostatic Bellows.

We have already learnt (§ 41) that in a liquid pressure is communicated throughout and in all directions. In Fig. 84 bellows (A) communicate with a narrow vertical tube BC. The whole apparatus is supposed to be filled with water. A considerable weight may be placed on the bellows and be supported by the pressure of the water in the tube BC. Let the area of cross-section of the tube be (say) 1 sq. cm. The pressure at the level LL_1A will be equal to pressure due to the column of water in BC (say) 50 cm. in height above this level. The upward pressure on A will therefore be 50 grams per sq. cm., and if the area of A were (say) 700 sq. cm., the total upward pressure on A will be

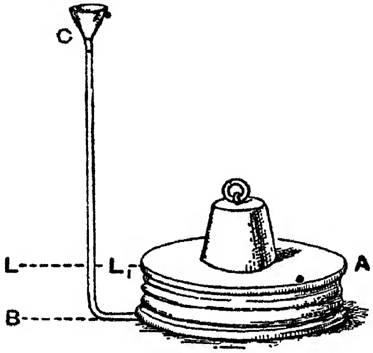


Fig. 84.

$$700 \times 50 = 35000 \text{ grams.}$$

Hydraulic Press. On this principle a hydraulic (Bramah's) press or a hydraulic lift is constructed. In the diagram (Fig. 85) a force pump with plunger or piston (P) of small area of cross-section can at low pressure produce a great total pressure on piston (Q) of large area of cross-section. Suppose, for instance, that the area of P is $\frac{1}{10}$ of the area of Q, then a force of F pounds on P will support a force (W) of $10F$ on Q.

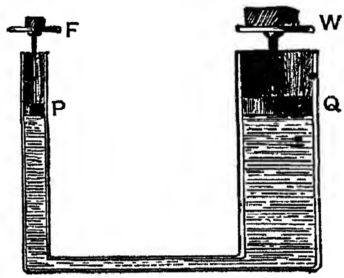


Fig. 85.

If P has an area of a units and Q has an area of A units, then (assuming the pistons are weightless and frictionless) F will support a weight $(W) = \frac{A}{a} \times F$, *i.e.* $F \times A = W \times a$.

67. Exercise (in designing). Design and draw to scale an apparatus suitable for compressing bales of cotton at high pressure. Apply the principle indicated in the last paragraph and calculate from your drawing the total pressure exerted by the larger plunger, if the pressure of the water produced by the smaller plunger (which is part of a force pump) is 250 pounds per square inch.

68. Siphon. A siphon is a bent tube (Fig. 86) used for conveying liquids from one vessel to another by aid of atmospheric pressure. Usually one arm (BC) of the siphon is longer than the other. Having filled the tube with water and having closed the end of the longer arm with the finger, open the shorter arm under water. The head of liquid between L_2 and C causes the liquid to flow in the direction BC.

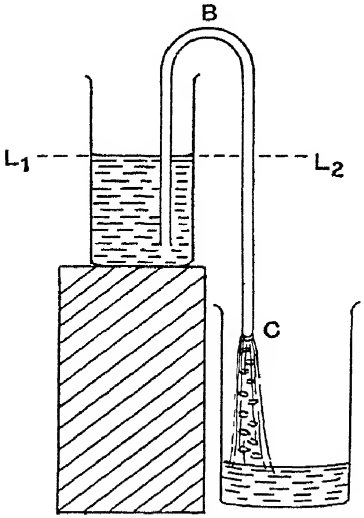


Fig. 86.

Let $L_1 L_2$ be the level of the surface of the liquid.

The pressure in the tube BC at L_2 = the pressure of the atmosphere (H).

The pressure in the tube BC at $C = H +$ the pressure downwards due to the liquid in the tube from L_2 to C.

$\therefore$ the liquid flows in the direction BC as long as C is below the level $L_1 L_2$.

69. The Diving Bell. If we take a tumbler and push it mouth downwards into a large beaker filled with water, we notice that air remains in the tumbler and that there is a slight rise of water in the tumbler as it is depressed further into the liquid. It is evident that the enclosed air is under a pressure which increases with the depth. In Fig. 87 is shown a diving bell

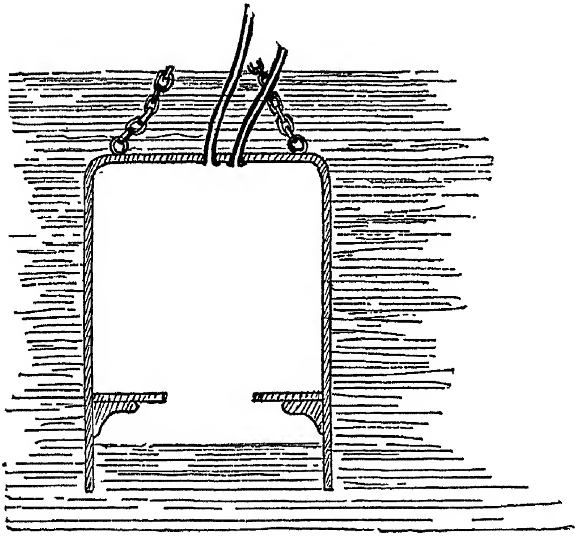


Fig. 87.

made on this principle. It is a large tumbler-shaped iron chamber, which may be lowered into water directly over some wreckage or a rock perhaps on which it may be necessary for men to work. Fresh air sufficient to cause free bubbling at the base must be pumped into the bell. Great discomfort is felt by men working at the high pressure which must be maintained to prevent water from entering the chamber from below even at moderate depths, but at depths up to 30 or 40 feet (*i.e.* at a pressure of 2 atmospheres) pain is only felt when the depth is changing.

EXAMPLES XI (MISCELLANEOUS QUESTIONS).

1. A piece of silver whose volume is 20 c.c. weighs 210 gm. The volume of a piece of aluminium weighing 2 Kgm. is 800 c.c. What are the densities of silver and of aluminium? What would you expect a solid block composed half of silver and half of aluminium to weigh if its total volume were 60 c.c.? O. J.

2. An aluminium weight of 100 gm. is attached to a cork. What must be the weight of the cork in order that the combined aluminium and cork may float in water totally immersed? Relative density of aluminium = 2·5: cork = 0·24. O. J.

3. How much water must be added to 50 c.c. of alcohol of density 0·82 gm. per c.c. to make a mixture of density 0·9 gm. per c.c.?

4. A glass stopper weighs 10·25 gm. in air, 6·15 gm. in water, and 6·97 gm. in methylated spirit. Calculate the relative density of glass and of spirit.

5. Find the relative density of pine-wood given that weight of wood alone = 4·08 gm.: weight of wood in air and sinker in water = 14·905 gm.: weight of sinker and wood in water = 6·405 gm.

6. 1 c.c. of lead (rel. density 11·4) and 21 c.c. of wood (rel. density 0·5) are fixed together. Show whether they will float or sink in water. O. J.

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7. A piece of sulphur weighs 12·2 gm. in air, 6·1 gm. in water and 6·71 gm. in oil. Calculate the relative density of sulphur and of oil.

8. Find the relative density of cork from the following: weight of cork alone = 0·89 gm.: weight of cork in air and sinker in water = 20·56 gm.: weight of cork and sinker in water = 17 gm.

9. A beaker of water is placed on the pan of a balance and counterpoised. A cube of copper of 2 cm. side is suspended from a separate support so that it is immersed in the water. What weight will be required to restore equilibrium and in which pan must it be placed?

10. If the hydrostatic bellows has a surface of 1 sq. ft., to what height must the tube (1 sq. in. cross-section) be filled with water in order to support a man weighing 10 stone?

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11. A metal cylinder 1 cm. in diameter and 15 cm. long weighs 122 gm. What is its density? Find to what extent it sinks or swims in mercury of density 13·6.

12. A piece of glass weighs 7·5 gm. in water and 8·1 gm. in turpentine of density 0·88 gm. per c.c. Find the volume and weight of the glass.

13. A Nicholson Hydrometer weighing 84 gm. requires 2·1 gm. to sink it to the mark in alcohol and 21 gm. when placed in water. Calculate the relative density of alcohol.

14. What is the pressure of the atmosphere in grams per sq. cm. when the barometer stands at 700 mm.? O. J.

15. A Bramah Press has two pistons of radii 2″ and 6″. If 10 lbs. be applied to the smaller piston, what pressure will the larger exert?

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16. If a cubic foot of water weighs 62·5 lbs. and a cubic inch of gold 0·698 lb., what is the specific gravity of gold? O. J.

17. If a mercury barometer registers 75 cm., what is the height of (*a*) a water barometer, (*b*) a glycerine barometer (density 1·25 gm. per c.c.)?

18. What weight of water fills a cylindrical tumbler of diameter 2·2 inches, height 4 inches? What is the pressure of the air on the surface of the water if the barometer stands at 30 inches?

19. In Hare's apparatus the height of a column of brine is found to be 35 cm. while the water column is 39·2 cm. Calculate the relative density of the brine.

20. To what depth must a diving bell 9 ft. high be sunk that the water may rise 3 ft. in it? (Barometer height=30″.)

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21. What will an ebony cylinder of height 7 cm. and diameter 3 cm. weigh in air and in water if the density of ebony is 1·2 gm. per c.c.?

22. What weight of lead $\frac{1}{11}$ inch thick is required to cover a hemispherical dome of diameter 11 ft.? (Density of lead=11·4 gm. per c.c.)

23. A bottle weighs 115·91 gm. when full of water and 97·8 gm. when full of alcohol of density 0·8 gm. per c.c. Find the weight of the bottle.

24. 21·65 gm. are needed to sink a Nicholson Hydrometer to the mark in water. With a piece of cryolite in the upper pan 19·62 gm., with the cryolite in the lower pan 20·3 gm., are needed. Calculate the relative density of the cryolite.

25. If 5·6 lbs. applied to the smaller piston (diameter 4″) of a Bramah Press causes a pressure of 1 ton on the larger piston, what is the diameter of the latter?

REVISION QUESTIONS.

PAPER A.

1. Write out the Metric Table of Length and give rough values for all the units. What was the metre originally intended to be?

2. Explain 'Parallax Error' by means of a diagram. How can it be avoided?

3. What is a Vernier? How would you make one to read to tenths of a millimetre?

4. State various methods for finding the circumference and diameter of a penny.

5. What is (*a*) a parallelogram, (*b*) a trapezium? How may their areas be determined?

6. Give sketches of apparatus used in the laboratory for measuring the volume of liquids.

7. What do you mean by 'Absolute Density,' 'Relative Density,' 'a litre,' 'Archimedes' Principle'?

8. Describe the process by which you would find the relative density of a piece of rock. O. J.

PAPER B.

1. Write out the Metric Table of Area.

2. Give a sketch of a pair of Callipers and explain how they are used to find the external and internal diameter of a tube.

3. What precautions must be taken when measuring the diameter of a wire by means of a Screw Gauge?

4. How could you prove that the area of a triangle is

$$=\frac{\text{perpendicular height} \times \text{base}}{2}?$$

5. If the radius of a circle is r, what will the circumference be? What do you mean by π?

6. Give any methods you know for obtaining the volume of a key and mention the chief sources of error in each method. C. J.

7. Explain fully how the relative density of a liquid may be found by the relative density bottle. Why is there a passage in the stopper?

8. Describe some experiment to prove Archimedes' Principle.

Paper C.

1. Write out the Metric Table of Volume.

2. Sketch and describe the Opisometer and explain how it is used.

3. How would you make a Wedge from squared paper by which the internal diameter of a glass tube may be found?

4. By what means can the length of a spiral coil of wire be found without unwinding it?

5. Suggest methods for finding the area (*a*) of an oak leaf, (*b*) of a field. What unit would you employ in each case?

6. How may the relative density of a liquid be found by means of a U-tube?

7. If the relative density of iron is 7·2, why can an ironclad ship float?

8. How would you determine the relative density of a piece of Rock Salt?

Paper D.

1. Write out the Metric Table of Weight.

2. How could the length of a racing track be found by means of a bicycle with a white patch on the tyre?

3. Sketch and describe a Spherometer and explain how it is used.

4. How could you prove that the area of a circle is πr^2.

5. What is 'Hare's Apparatus'? How is it used for finding the relative density of a liquid?

6. Describe some experiment to prove that the pressure of a liquid on a surface immersed in it depends upon the depth.

7. Distinguish between the *Mass* of a body and its *Weight*, and explain how each is measured. At what part of the earth's surface will a mass of 10 stone have the greatest weight? Give reasons for your answer. O. J.

8. Under what circumstances does a solid float in a liquid? A cubical box measuring 3 cm. each way just floats in water with one face level with the surface. How heavy is it? Explain exactly how you get your result. What will happen if the water is warmed slowly? O. J.

PAPER E.

1. What is the area of a Sphere? By what experiment could you verify your answer?

2. How may it be shown that the area of the curved surface of a cone is $=\frac{1}{2}$ circumference $\times$ slant height?

3. Sketch a Balance and name the various parts, explaining the use of each.

4. Describe the construction and explain the use of a simple mercurial barometer. C. J.

How would you prove that the space above the mercury is a vacuum?

5. Explain how you would find, by the Principle of Archimedes, the relative density (*a*) of a solid lighter than water, (*b*) of a liquid. O. J.

6. What do you mean by a fluid? State the distinction between solids, liquids and gases.

7. How is it shown experimentally that if a pressure of any amount is applied to the surface of a liquid the liquid transmits this pressure to every surface in contact with it? O. J.

8. Explain, with diagrams, the action of 'Suction' and 'Force' Pumps. Why can water only be raised about 30 ft. with an ordinary pump?

PAPER F.

1. How may the weight of a litre of air be determined experimentally?

2. Sketch an arrangement by which you would show that the intensity of pressure is the same at all points at the same depth in water. O. J.

3. Describe with sketch and brief explanation an 'exhausting' air pump. O. J.

How would you use it to prove that the mercury in a barometer is supported by the Atmospheric Pressure?

4. In a beaker containing water floats a sphere of wood. If the vessel is put inside the receiver of an air pump what will happen to the wood (*a*) if the air is exhausted, (*b*) if more air is forced in? Give reasons.

5. Explain the action of a Siphon.

6. State the 'Principle of Archimedes' and apply it to a balloon. Explain why a balloon first rises rapidly and finally ceases to rise.

7. Describe Nicholson's Hydrometer. How is it used for finding the relative density (*a*) of a solid, (*b*) of a liquid?

8. Give a diagram of an Aneroid Barometer and explain its action. What is the meaning of the word 'aneroid'?

Paper G.

1. What is meant by (*a*) a sidereal day, (*b*) a mean solar day, (*c*) a second?

2. How would you prove that the time of oscillation of a pendulum is independent of the 'amplitude' of vibration when the amplitude is small?

3. Sketch and describe Fortin's Barometer.

4. The relation between the length of a pendulum (l) and the time of a complete oscillation 'to and fro' (t) is given by the equation

$$t=2\pi\sqrt{\frac{l}{g}},$$

where $g=981$ when l is measured in cms.,

$= 32$ „ l „ ft.

If the lengths of two pendulums are 100 cm. and 81 cm., compare the times taken by each in making 40 oscillations. Confirm your results by referring to the curve on p. 15.

5. Explain the action of Sprengel's Vacuum Pump.

ANSWERS TO EXAMPLES.

Examples VII.

1. 11 cm. 2. 1·46 gm. 3. 39·325 gm. 4. 1·6 cm.
5. 1033·6 gm. 6. 96 kgm.; 40 gm. 7. 250 lb. 8. 2·5 cm.
9. 69·7 kgm.; 51·25 m. 10. 34·56 ft. 11. 0·91. 12. 10 cm.
13. 50 cm.

Examples VIII.

1. 8·9. 2. 59·94 gm. 3. 2·7 gm. per c.c. 4. 124 kgm.
5. 2·5 gm. per c.c. 6. 10·5. 7. 40·61 gm. 8. 160 gm.; 96 gm.
9. 3 c.c. 10. 189 lb. 11. 7·3 gm. per c.c. 12. 2·1 gm. per c.c.
13. 10·24 gm. 14. 1·4 cm.

Examples IX.

1. 5·7 c.c.; 4·3 gm. 2. 0·51. 3. $\frac{19}{31}$. 4. 4789·7 cu. yds.
5. 15 cm.; 0·878. 6. 8 c.c. 7. 716,800 cu. ft. 8. 1·512 ft.
9. 1·12; 16·47 cm. 10. 1·2. 11. 8·9. 12. 10·1 gm.

Examples X.

1. 0·00125 gm. per c.c.; 71·24 gm. 2. 201·6 kgm. 3. 1·27 gm.
4. 81·293 gm. 5. 12·03 gm. 6. 0·819. 7. 28·7 cm.
8. 47·5 c.c. 9. 15·2 cm.; 70$\frac{2}{3}$ cm. 10. 880 c.c.; 346·75 c.c.

Examples XI.

1. 10·5; 2·5; 390 gm. 2. 18·95 gm. 3. 40 gm. 4. 2·5; 0·8.
5. 0·48. 7. 2; 0·9. 8. 0·25. 10. 26·88 in.
11. 10·35 gm. per c.c. 12. 5 c.c.; 12·5 gm. 13. 0·819.
14. 952 gm. 15. 90 lb. 16. 19·3. 17. 1020 cm.; 816 cm.
18. 0·55 lb.; 57 lb. 19. 1·12. 20. 11 ft. 21. 59·4 gm.; 9·9 gm.
22. 1026 lb. 23. 25·36 gm. 24. 2·985. 25. 80 in.

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